Uplink CoMP Capability Improvements In Heterogeneous Cellular Networks

Politecnico di Torino

Department of Electronics and Telecommunication

Uplink CoMP Capability Improvements

In Heterogeneous Cellular Networks

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To My

My Parents

Final Thesis 2016

Acknowledgment

This dissertation would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study.

First and foremost, my utmost gratitude to Professor Claudio Casetti whose sincerity and encouragement I will never forget. Dr. Fabrizio Gatti has been my inspiration as I hurdle all the obstacles in the completion this research work. I am highly thankful to Maurizio Fodrini and Marco Caretti whose invaluable guidance helped me understands the project better and particular thanks are due to eng. Loris Bollea.

I am also deeply indebted to all the other tutors and researchers of the Telecommunication Network Group- TNG and Telecom Italia –TIM for their direct and indirect help to me.

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Introduction and Goals of the thesis

LTE-Advanced meets the challenge raised by powerful, mobile devices and bandwidth-hungry applications by investing in solutions such as carrier aggregation, higher order MIMO, relay nodes and Coordinated Multipoint (CoMP) transmission/reception. The latter, in particular, is envisioned to be one of the most important techniques in LTE-Advanced to improve the throughput and functionality of cell borders. CoMP allows users to have multiple data transmission and reception from/toward multiple cooperating eNodeBs (eNBs), increasing the utilization factor of the network. Resource allocation in the uplink is especially beneficial because more sophisticated algorithms can leverage the availability of additional connection points where the signal from the User Equipment (UE) is processed, ultimately providing UEs with increased throughput. Additionally, a significant part of the interference caused by neighboring cells can be seen as a useful received signal thanks to CoMP, provided those cells are part of the Coordinated Reception Point (CRP) set. This is especially important in critical regions, in terms of interference, like cell edges. Finally, in the case of joint multi-cell scheduling, CoMP introduces a reduction in the backhaul load by requiring only scheduling data to be transferred between coordinated eNBs.

Arguably, CoMP is most appealing in the uplink direction since it does not require UE modifications: indeed, users need not be aware that there is any kind of cooperation among receiving eNBs. UEs are merely scheduled for transmission on a set of frequencies that happens to be split among different eNBs, although they still retain standard signaling channels through only one of these eNBs, usually referred to as the serving cell.

In this work we focus on uplink CoMP from a system point of view. Specifically, we are interested in comparing through simulation the performance of uplink CoMP in various scenarios with different user participation to CoMP transmissions and CoMP margins. Some works have already investigated uplink CoMP both in simulation and through field trials. Our contribution confirms the findings of previous works as far as the throughput gain for edge users is concerned, but introduces three novel observations that can spur future investigations on CoMP systems, in both downlink and uplink regime, and lead to the design of new resource allocation algorithms:

- We look at Heterogeneous scenario where there is no restriction in the type of cells that can be in the CRP set, but simultaneously we introduce clustering option included limited number of Macro and small cells to be acted independently from other clusters in CoMP process.
- We introduce a parameter called CoMP Pool Percentage (CPP), which quantifies the fraction of PRBs that are reserved for UEs using a specific eNB

as CRP (out of the resources nominally available to that eNB). Our algorithm show that the setting of CPP must be carefully gauged depending on the number of CoMP users and the scenario.

- We proposed an innovative dynamic algorithm to make decision of the CPP value in order to improve the gain for CoMP users while considering the whole network gain.

Combination of the three above mentioned routine and algorithms, according to simulations, confirms an average gain of at least 20% percent for the CoMP users, (average over various population) locating in cell boarder, while the whole network benefits by average of 5% gain for all the users (see results section). The algorithm also guarantees more gain for more values of CoMP margin. In other words, the more the population of CoMP users locating in cell borders the more would be the achievable gain.

Objectives

Objectives of this PhD thesis are concluded as follows:

- Design a Network-level simulator whose features are close to a real LTE network, including advanced capabilities and innovations
- Observe the response of the network to parameters changes
- Increase the throughput gain (using CoMP vs. non using it) and the quality of service
- Design and evaluate the Novel Scheduling Algorithm
- Compare the obtained results with real cases

LTE Advanced

Long-Term Evolution (LTE) allows operators to use new and wider spectrum and complements 3G networks with higher data rates, lower latency and a flat, IP-based architecture. To further improve the broadband user experience in a ubiquitous and cost-effective manner, 3GPP has been working on various aspects of the LTE Advanced standard.

Since radio link performance is fast approaching theoretical limits with 3G Enhancements and LTE, the next performance leap in wireless networks will come from an evolved network topology. The concept of LTE Advanced-based Heterogeneous Networks is about improving spectral efficiency per unit area. Using a mix of macro, pico, femto and relay base stations, heterogeneous networks enable flexible and low-cost deployments and provide a uniform broadband experience to users anywhere in the network. To enhance the performance of these networks, advanced techniques are described, which are needed to manage and control interference and deliver the full benefits of such networks.

Range expansion allows more user terminals to benefit directly from low-power base stations such as picos, femtos and relays. Adaptive inter-cell interference coordination provides smart resource allocation amongst interfering cells and improves inter-cell “fairness” in a heterogeneous network. In addition, the performance gains possible via heterogeneous networks are shown using a macro/pico network example.

Most important aims of LTE-A are listed as follows:

- Higher capacity and bitrates in a cost efficient way.
- Increased peak data rate, DL 3 Gbps, UL 1.5 Gbps and higher spectral efficiency
- Increased number of simultaneously active subscribers
- Improved performance at cell edges

Most Important Features

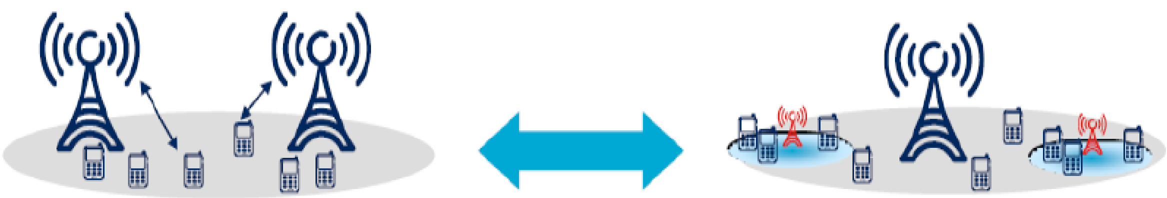
- Carrier Aggregation
- MIMO
- Relay Nodes
- Coordinated Multi Point operation (CoMP)

Heterogeneous Network

To achieve performance improvements in LTE Advanced, the 3GPP has been working on various aspects of LTE including higher order MIMO (multiple antennas), carrier aggregation (multiple component carriers), heterogeneous networks (picos, femtos and relays) and coordinated multipoint functionality (CoMP). Since improvements in spectral efficiency per link are approaching theoretical limits with 3G and LTE, the next generation of technology is about improving spectral efficiency per unit area Heterogeneous networks.

In other words, LTE Advanced needs to provide a uniform user experience to users anywhere inside a cell - by changing the topology of traditional networks. The key benefits of LTE Advanced in heterogeneous network deployments are highlighted in the discussion that follows. Therefore, Het-Net, are considered as a standard part of future mobile networks. Generally speaking, expansion of mobile network capacity and frequency efficiency by means of following procedures.

- Increased data rates
- Expanded cell coverage and indoor coverage
- Reduced user rate starvation
- Different transmit power – Energy Efficiency
- Reduce load on Macro cells



Traditional Network Deployment Approach

Current wireless cellular networks are typically deployed as homogeneous networks using a macro-centric planning process. A homogeneous cellular system is a network of base stations in a planned layout and a collection of user terminals, in which all the base stations have similar transmit power levels, antenna patterns, receiver noise floors and similar backhaul connectivity to the (packet) data network. Moreover, all base stations offer unrestricted access to user terminals in the network, and serve roughly the same number of user terminals, all of which carry similar data flows with similar QoS requirements.

The locations of the macro base stations are carefully chosen through network planning, and the base station settings are properly configured to maximize the coverage and control the interference between base stations. As the traffic demand grows and the RF environment changes, the network relies on cell splitting or additional carriers to overcome capacity and link budget limitations and maintain uniform user experience. However, this deployment process is complex and iterative. Moreover, site acquisition for macro base stations with towers becomes more difficult in dense urban areas. A more flexible deployment model is needed for operators to improve broadband user experience in a ubiquitous and cost-effective way.

An Alternate Approach Using Heterogeneous Network

Wireless cellular systems have evolved to the point where an isolated system (with just one base station) achieves near optimal performance, as determined by information theoretic capacity limits. Future gains of wireless networks will be obtained more from advanced network topology, which will bring the network closer to the mobile users. Heterogeneous networks, utilizing a diverse set of base stations, can be deployed to improve spectral efficiency per unit area.

Heterogeneous cellular system consists of regular (planned) placement of macro base stations that typically transmit at high power level (~5W - 40W), overlaid with several pico base stations, femto base stations and relay base stations, which transmit at substantially lower power levels (~100mW - 2W) and are typically deployed in a relatively unplanned manner. The low-power base stations can be deployed to eliminate coverage holes in the macro-only system and improve capacity in hot spots. While the placement of macro base stations in a cellular network is generally based on careful network planning, the placement of pico/relay base stations may be more or less ad hoc, based on just a rough knowledge of coverage issues and traffic density (e.g. hot spots) in the network. Due to their lower transmit power and smaller physical size, pico/femto/relay base stations can offer flexible site acquisitions. Relay base stations offer additional flexibility in backhaul where wired line backhaul is unavailable or not economical.

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Coordinated Multipoint

Coordinated Multi-Point transmission/reception (CoMP) is considered by 3GPP as a tool to improve coverage, cell-edge throughput, and/or system efficiency. The main idea of CoMP is as follows: when a UE is in the cell-edge region, it may be able to receive signals from multiple cell sites and the UE's transmission may be received at multiple cell sites regardless of the system load. Given that, if the signaling transmitted from the multiple cell sites is coordinated, the DL performance can be increased significantly. This coordination can be simple as in the techniques that focus on interference avoidance or more complex as in the case where the same data is transmitted from multiple cell sites. For the UL, since the signal can be received by multiple cell sites, if the scheduling is coordinated from the different cell sites, the system can take advantage of this multiple reception to significantly improve the link performance. In the following sections, the CoMP architecture and the different CoMP schemes will be discussed.

Downlink COMP

In terms of downlink CoMP, two different approaches are under consideration: Coordinated scheduling, or Coordinated Beam forming (CBF), and Joint Processing/Joint Transmission (JP/JT). In the first category, the transmission to a single UE is transmitted from the serving cell, exactly as in the case of non-CoMP transmission. However, the scheduling, including any Beam forming functionality, is dynamically coordinated between the cells in order to control and/or reduce the interference between different transmissions. In principle, the best serving set of users will be selected so that the transmitter beams are constructed to reduce the interference to other neighboring users, while increasing the served user's signal strength.

For JP/JT, the transmission to a single UE is simultaneously transmitted from multiple transmission points, across cell sites. The multi-point transmissions will be coordinated as a single transmitter with antennas that are geographically separated. This scheme has the potential for higher performance, compared to coordination only in the scheduling, but comes at the expense of more stringent requirement on backhaul communication.

Depending on the geographical separation of the antennas, the coordinated multi-point processing method (e.g. coherent or non-coherent), and the coordinated zone definition (e.g. cell-centric or user-centric), network MIMO and collaborative MIMO have been proposed for the evolution of LTE. Depending on whether the same data to a UE is shared at different cell sites, collaborative MIMO includes single-cell antenna processing with multi-cell coordination, or multi-cell antenna processing. The first technique can be implemented via precoding with interference nulling by exploiting the additional degrees of spatial freedom at a cell site. The latter technique includes collaborative precoding and CL macro diversity. In collaborative precoding, each cell site performs multi-user precoding towards multiple UEs, and each UE receives multiple streams from multiple cell sites. In CL macro diversity, each cell site performs precoding independently and multiple cell sites jointly serve the same UE.

Uplink COMP

Uplink coordinated multi-point reception implies reception of the transmitted signal at multiple geographically separated points. Scheduling decisions can be coordinated among cells to control interference. It is important to understand that in different instances, the cooperating units can be separate eNBs' remote radio units, relays, etc. Moreover, since UL CoMP mainly impacts the scheduler and receiver, it is mainly an implementation issues. The evolution of LTE, consequently, will likely just define the signaling needed to facilitate multi-point reception.

Objectives

The main idea and objectives of CoMP are as follows:

- Increase the throughput where signal quality is lower (cell edge)
- Better utilization of network
- Enhanced transmission and reception performance
- Multiple site reception increases received power
- Interference reduction

Chapter 1

In this chapter we are going to describe the definition and the requirement of the simulation and the project. First of all the description of the network layer will be expanded and then the basic definition and properties which are associated to cellular network and CoMP functionality will be identify separately.

Cell Type

Since the basic of the project is about heterogeneous different type of cells contributing according to better simulation this kind of infra structure

1. Microcell is a cell in a mobile phone network that provides radio coverage served by a high power cellular base station. Generally, Microcells provide coverage than other kind of cells. These cells usually provided with base station transmission facilities, antenna and front end modules. Unlike the other kind of lower power cells according to the transmission power and placement of these cells they have to be deployed in the field. According to the specific planning to be parallelize with 3GPP standard each microcell is provided with a 3 lobe irradiation pattern. Usually the transmission power of microcell is between 30 up to 43 DBM and it can be individually set in the simulation.
2. Small Cell deployment of and heterogeneous network would not be visible without the proper usage smaller cells with the lower power. Generally speaking we categorize microcells, Pico cells, and Femto cells as a low power small cell in our simulation. Associated transmission power to small cells is usually below 30 dBm. Omni directional radiation pattern is consider for this kind of cells. Deployment tragedy for small cells, in this simulation, is rather arbitrary or according to the hotspot placement.

Network Layer Description

Field Dimension

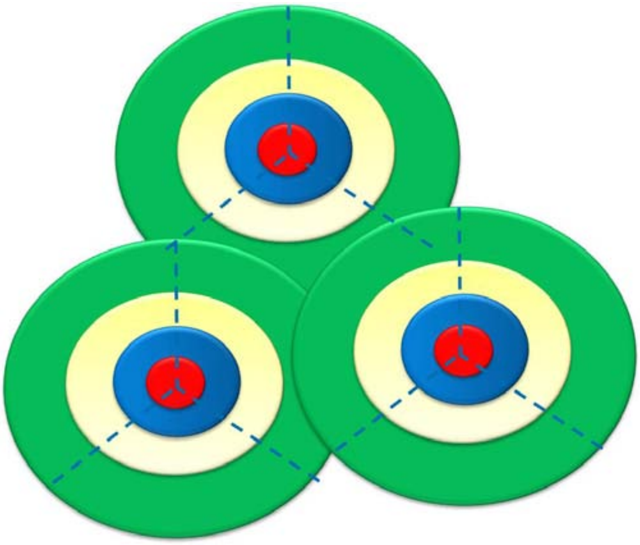
In the first set of simulation we proposed to cover an area of 3km by 3km. Total number of microcell and small cell are set to 15, 25, 50 and 75 respectively. Associated power to micro cell is equal to 30 watt and small cells transmit 1 watt continuously. Fixed value of 9dB is considered as a CRE function in cell selection process by users. In this set of simulation micro cell deployment is based on maximum preferable of intra distance. Deployment algorithm for according to the placement of cells is based on a recursive strategy to prevent the allocation of the similar cells to be near each other or to be distanced less than a certain value.

Cell deployment strategy

Since we use similar processes to place the Macro and Pico cells, the routine is just described for Macro cells. According to the area size and number of macro cells, in this program we tried to place the eNBs as separate as possible. The placement algorithm guaranties the maximum possible distance between the Macro cells. Considering that M macro cells should be places within a S square kilometers of area, the target minimum distance between each pair of macro cells should be $d = \sqrt(s/M)$. Assignment of the first Macro cell is completely random. The algorithm places next macro cells with mentioned minimum distance up to the point that the condition is not satisfied anymore. Then the program locates the eNBs according to the fractions of the value of minimum distance around the located eNB. Therefore placement priorities are assigned with the portions of the minimum distance of d, for example:

$$\sqrt{\frac{S}{2*M}} < 2_{nd}PriorityRegion < d_M$$

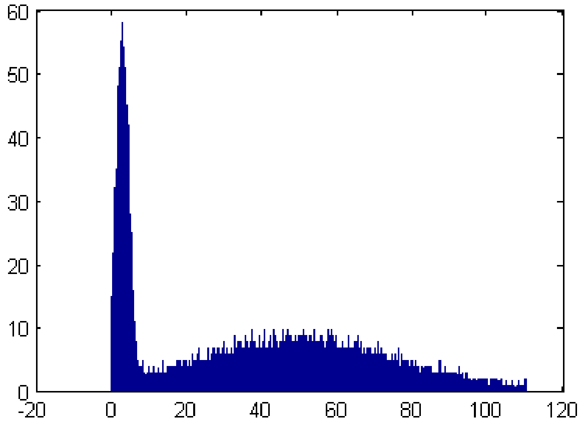
According to users, first places distribution is done by recursive process with the limitation of the associated minimum distance.



Distribution of eNBs and Priority regions

User's distribution and associated Velocities

The area is assumed to be populated by 1,000 or 2,000 UEs moving according to a simplified random direction model, where UE speed is constant and direction changes every 1s. The speed is randomly chosen for every UE according to a Gaussian distribution. The associated mean value of the Gaussian distribution is set to 3 km/h (slow UEs) and 50 km/h (fast UEs), with a standard deviation of 1.5 and 20 Km/h. The distribution of UE speed in our simulations is depicted in Figure below.



In order to maximize the effectiveness of small cell coverage, a {hotspot} is defined within a 200m radius of each small cell. In each simulation, 60% of slow UEs are placed within the hotspot.

RSRP Calculation and Pathloss Models

There are three major factors which should be taking into account for calculation of the RSRP.

Relative Distance: After assignment of Macro and Pico places and users locations in different time frames, Distances between each user and each eNB (Macro or Pico cell) is calculated by the program. This item is going to be used as one of input parameters to calculate the Path-loss.

Pathloss Model: Three different pathloss models can be applied in order to obtain the RSRP. Line of sight model (Friis) and model with different pathlosses for macro and pico cells and "other user defined" models

1. *Friis model*: This formula is the regular line of sight pathloss calculation which is shown in follows:

$$PL_{db} = 32.45 + 20 * \log_{10}(Freq) + 20 * \log_{10}(Dis)$$

2. *Our used model*: In this model the path-loss associated to macro and Pico cells are different.

where for Macro cells:

$$PL_{Macro,db} = 140.7 + 36.7 * log_{10}(Dis)$$

and for Pico cells:

$$PL_{Pico,db} = 128.1 + 37.6 * log10(Dis)$$

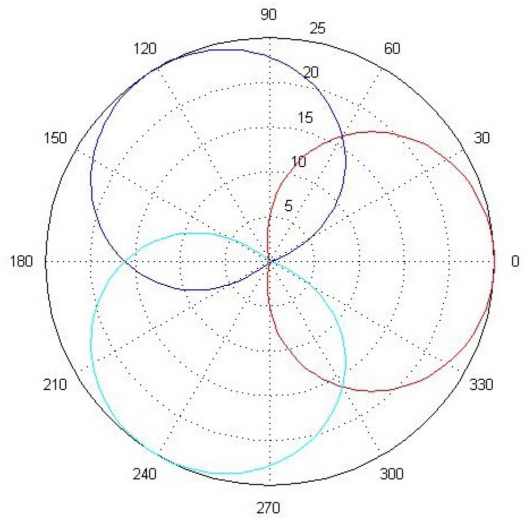
3. *Other Models*: Other path-loss models (like HATA cost 231 , Egli and etc.) can be set as an input of the can be set as an input of the program in case of special uses.

Relative Angle and Antenna Pattern: Each Macro station has three Macro cells covering all 360 degree around the Macro station. According to the antenna pattern for each Macro Cell, The Pattern of the cells is also affect the value of RSRP. Calculation of an antenna Pattern is done by formula below:

$$A(\phi) = -\min\left[12\left(\frac{\phi}{\phi_{3dB}}\right), A_m\right]$$

where:

$$\phi_{3dB} = 70^\circ, -180^\circ < \phi < 180^\circ\ ,\ A_m = 20dB$$



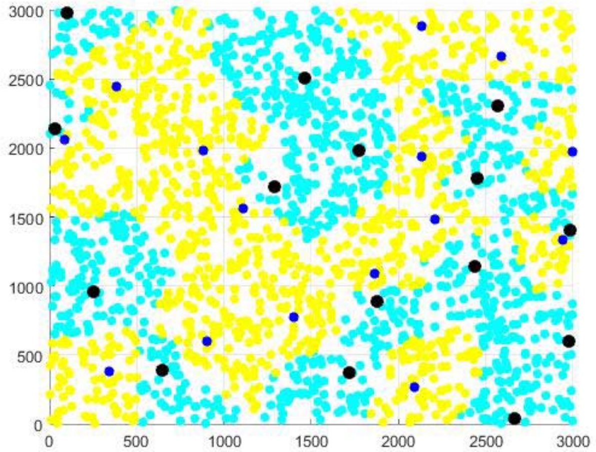
According to Pico or small cells, we decide to consider an omni-directional pattern with the gain of 0dB for each eNB.

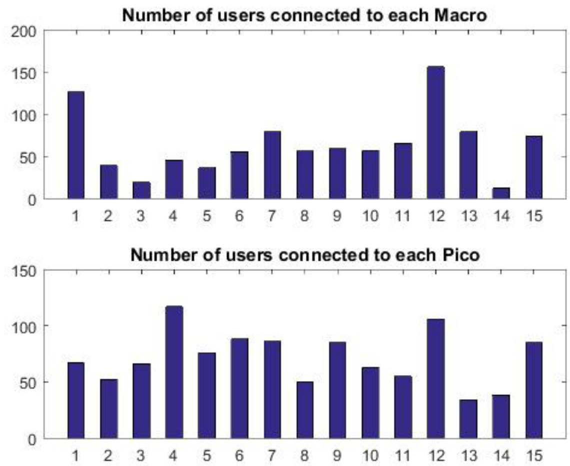
Capacity Evaluation in different scenarios according to the number of Macro and small (pico) cell – interference impact

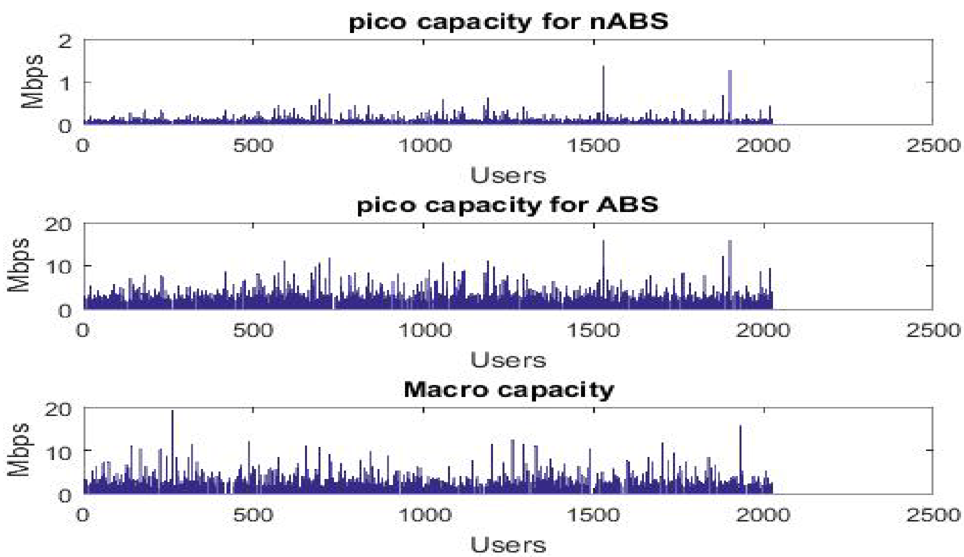
We decide to observe the capacity of the network according to Shannon formula to evaluate the performance and decide the best number of eNBs to deploy. To this aim, we simulate the different scenarios in terms of eNB quantities. In the simulation, we focus of connection between users and heterogeneous network. The first graphs show the distribution of the eNBs and users, big black and blue dot are representatives of Macro and small cell respectively. Cyan and yellow small dot are user connecting to Macro or small cells as well. Second graphs shows the population of the users connection to each eNB in both cases of Macro and small (pico) cells.

Last graph in each set shows the capacity of each connection according to each eNB for Macro and Pico cells connection. The capacity of the network was also evaluated in ABS condition which the interference value is reduced.

Results







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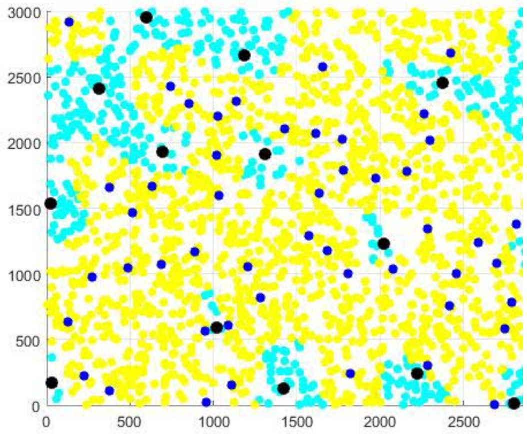
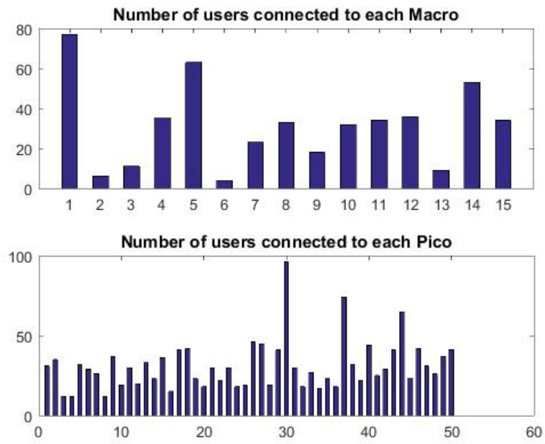
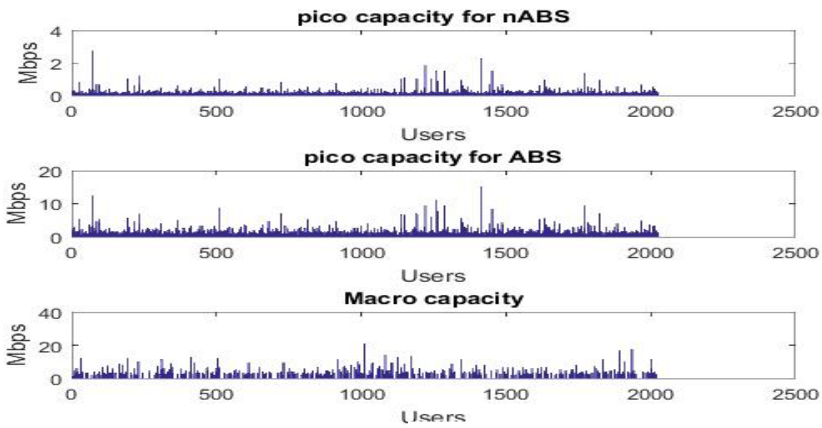
Pico = 15







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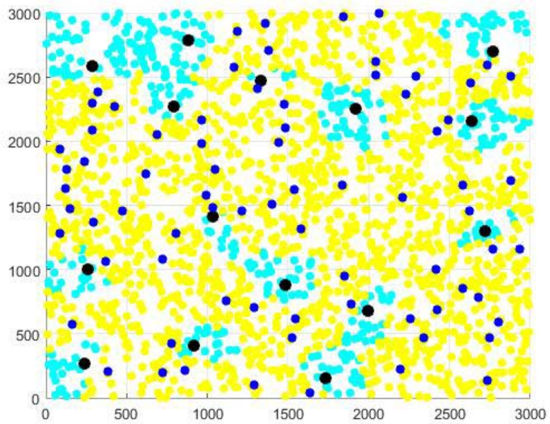
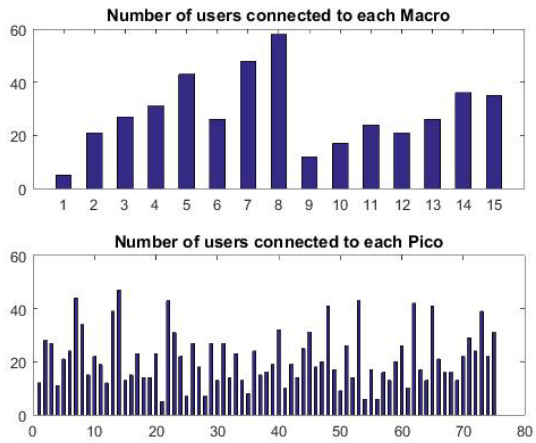
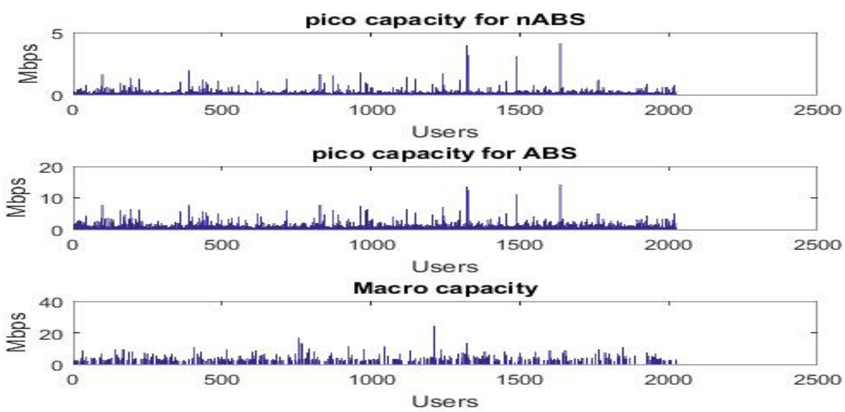
Pico = 50

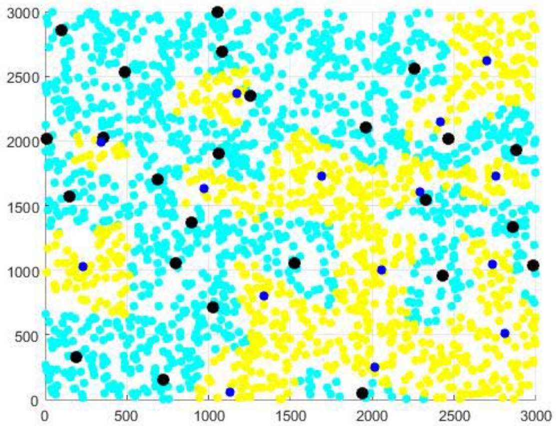


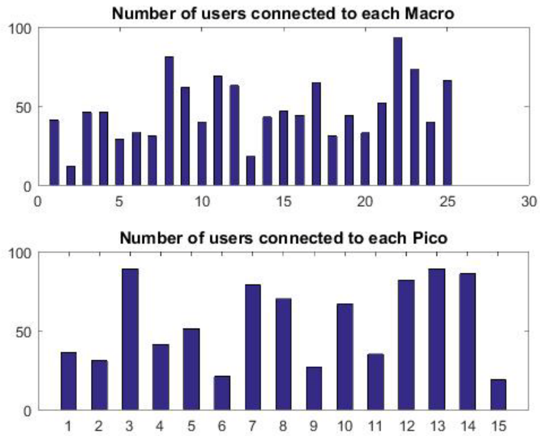


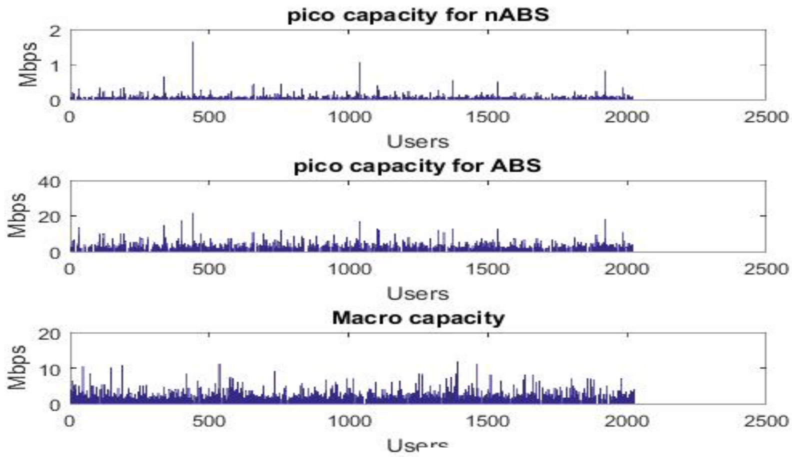


Macro = 15

Pico = 75

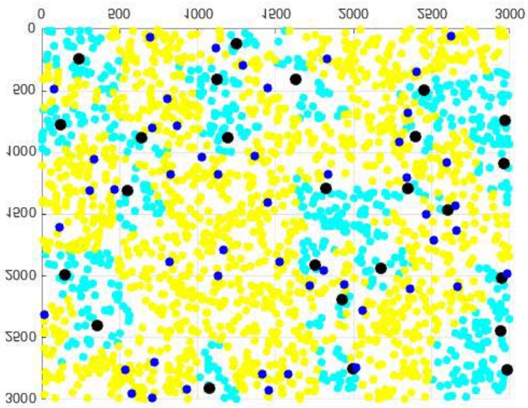


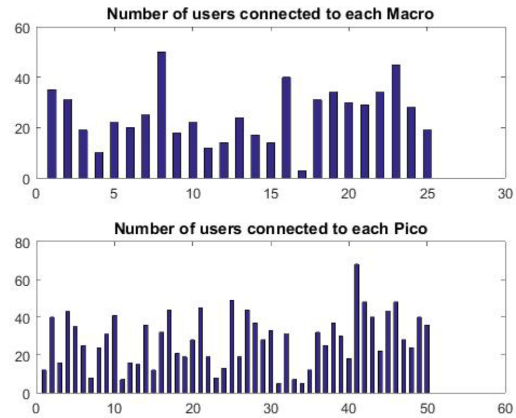


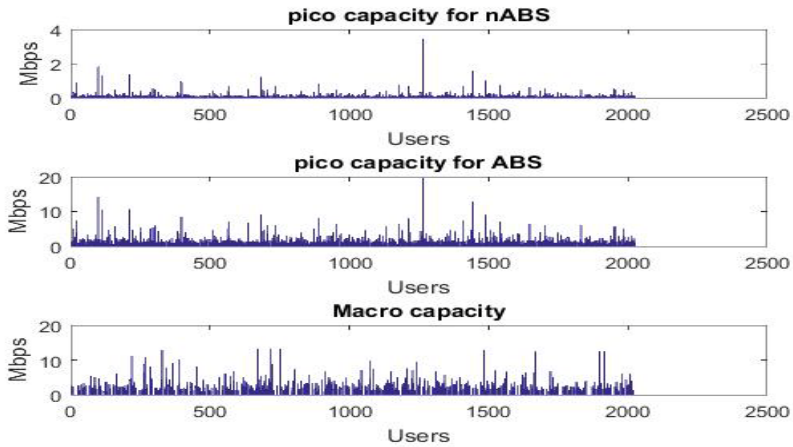


Macro = 25

Pico = 15







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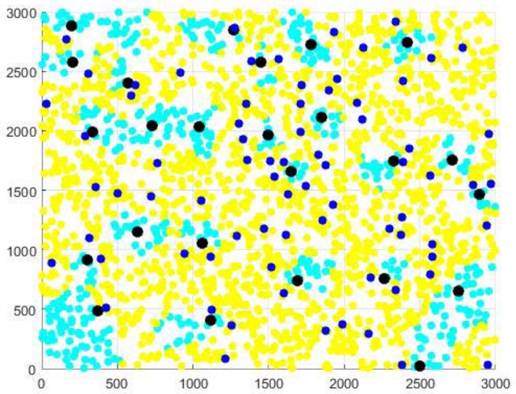

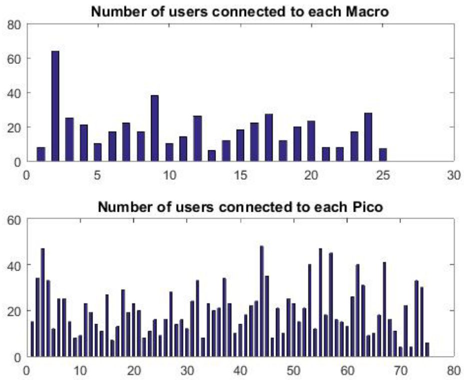

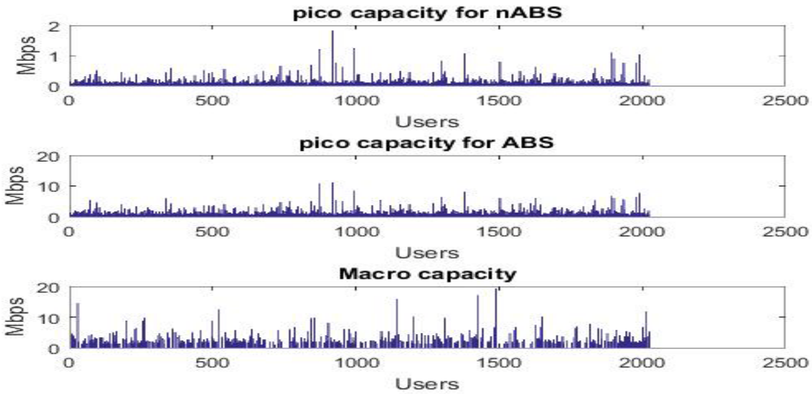

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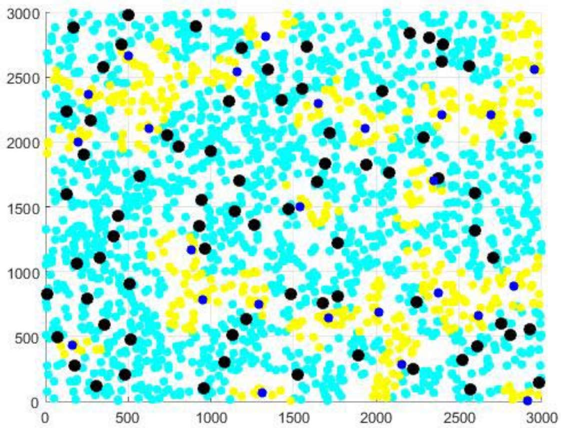
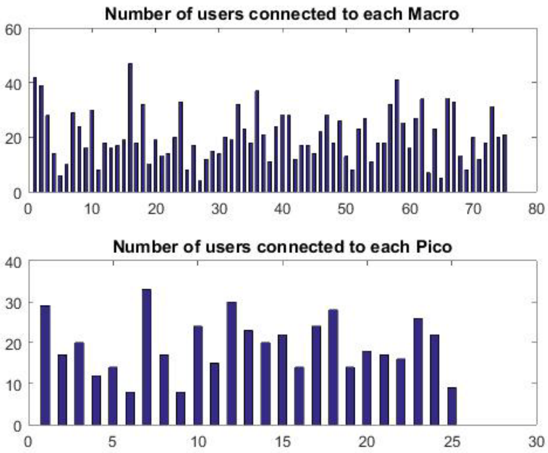
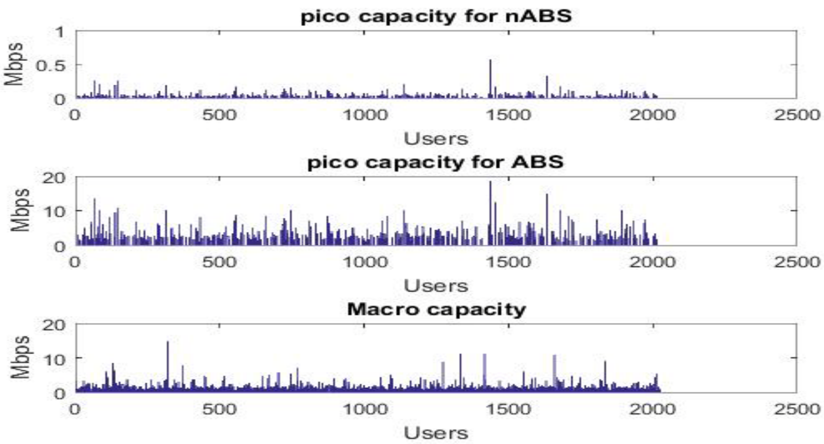
Pico = 75







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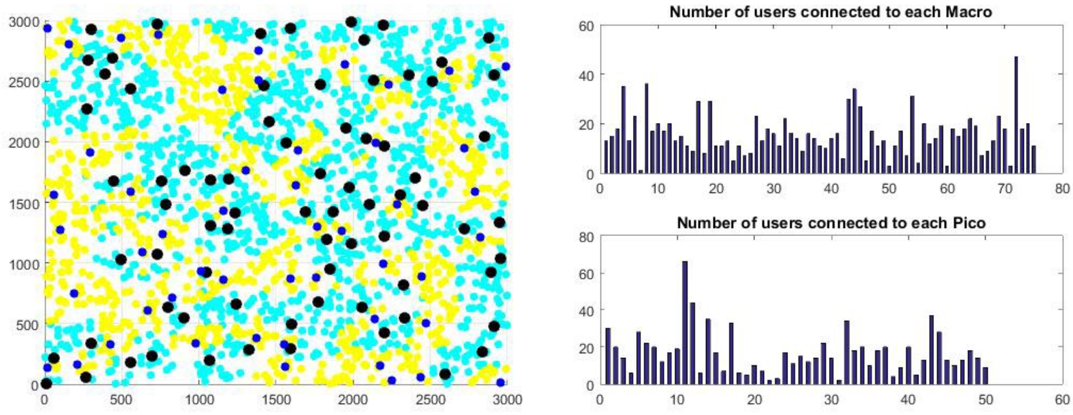
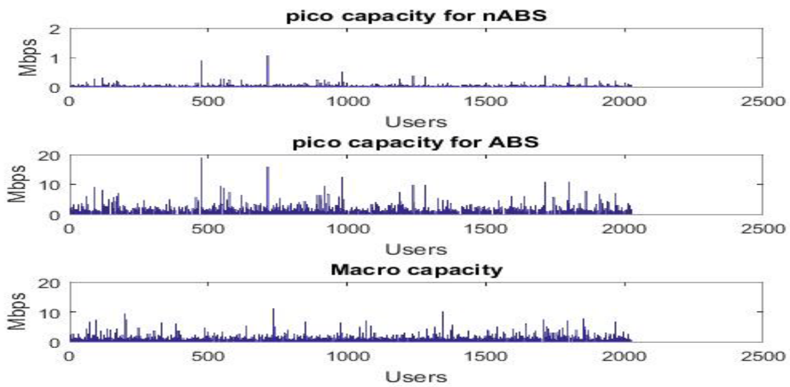
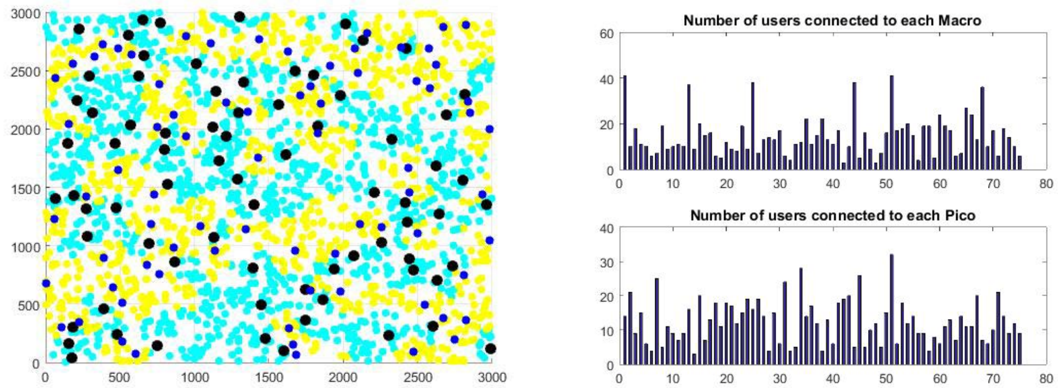
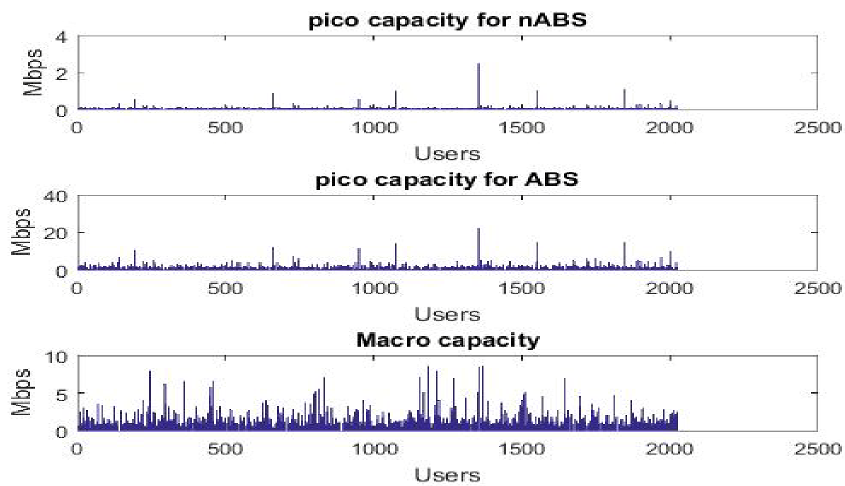




Macro = 75

Pico = 50





Macro = 75

Pico = 75

Chapter 2

Fast fading

We model fast fading effects due to multipath using a frequency-selective Rayleigh model. Since the average distance between mobile users and eNBs is less than 150 meters, a multipath pattern with attenuation and five different delay taps, bounded at 110 ns, are set as an input for the Rayleigh fading process. Values of delay and attenuation are taken from the Extended Pedestrian A model (EPA). Although in the original model the number of taps is equal to seven, for the sake of simulation time and average distance, we decide to use just first five taps. Considering our scenario featuring high-speed and low-speed users (CoMP being used mainly by the latter), the maximum value of the Doppler spread for CoMP users can be computed as:

$$\Delta F_{dopp} = \frac{V}{\lambda}$$

Where V and lambda are the relative mobile user velocity and central carrier frequency wavelength, respectively. With the numerical values used in our scenario, Doppler is less than 100 Hz. We thus assume that the fading process is approximately constant over a 10-ms coherence time.

In order to simplify the simulations, we compute the fading losses every 10 ms instead of the TTI value of 1ms (Block Fading). A further simplification we introduce is the computation of fading loss from only 10 randomly selected PRBs, out of 100 PRBs. Thus, the expression of fading loss used in the computation of the Reference Signal

Received Power (RSRP) between user *i* and n_{th} eNB is computed as:

$$A_{n,i} = \frac{\sum_{PRB \in B} R_{loss}(n,i)}{10}$$

Since we still do not schedule users in terms of frequency, physical resource block, the average of fading loss over ten semi-randomly selected PRBs is considered as a fading loss factor for cell selection strategy. Having a total number of 100 PRB, in each iteration, the process randomly select ten PRBs with inter distance of 10 PRB. For example program may choose 4th, 14th, 24th, .., 94th as candidates PRBs for the mentioned calculation.

CoMP Scenarios

Uplink CoMP relies on measurements reported by the UE through standard signaling channels, comparing the received power of the candidate CoMP Reception Point (CRP) cell and that of the serving cell. If the RSRP of the CRP cell is higher than the RSRP of the serving cell minus a quantity called CoMP margin (measured in dB), then the candidate is selected as CRP. Intuitively, the higher the CoMP margin, the larger would be the number of UEs who satisfy the condition to become CoMP users. If more than one cell satisfies the condition, the CRP are selected in increasing order of RSRP values, up to 3 CRP cells.

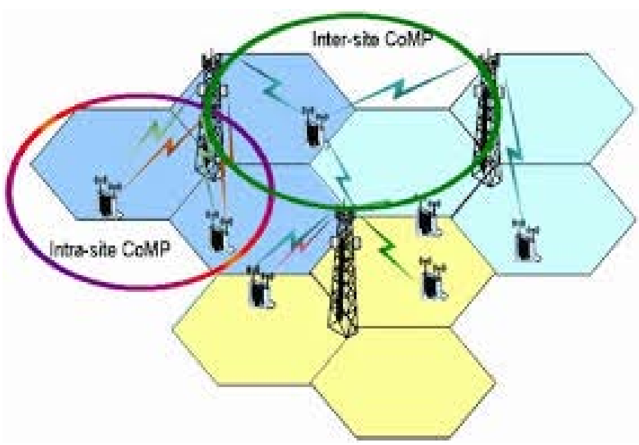
Since backhaul conditions are not modeled in our simulations, the CoMP margin value does not depend on the network load, a feature that we will explore in future work. Likewise, the CoMP margin does not depend on cell sizes. In our simulations, we consider four scenarios where macro and small cells can play different roles, as either serving cells or CRPs, or both. We acknowledge that each scenario entails the selection of different signaling overhead, which we however consider as negligible since we do not model the backhaul.

- **Intra** CoMP is enabled just for one of the non-serving cells of the same eNB where the serving cell is located. In this case, the maximum number of CRPs is limited to 2 and no small cell is involved as CRP. A small cell can be a serving cell in this scenario, but the user transmitting to it cannot use CoMP.

- **Inter** CoMP is enabled for cells from any macro eNB, not restricted to cells of the serving eNB. Small cells cannot be used for CoMP.

- **Small** although any cell can be a serving cell, only small cells can be CRP.

- **Het** no restrictions in the roles of serving and CRP.



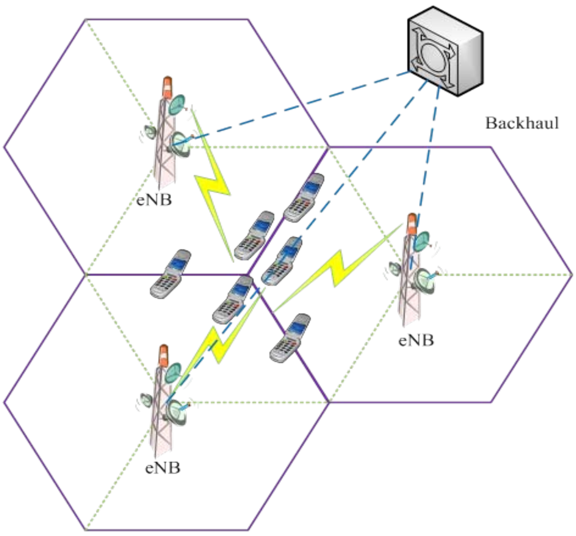
CoMP Margin and Bias

Coordinated multipoint should happen when the received power of the CRP cell is within the certain range of the serving cell. This condition implies the cell edge condition where, received RSRPs from two cells, serving and CRP are in the same order. This region is exactly the region of interest where CoMP has the highest efficiency. Intuitively, the higher the CoMP margin, the larger would be the number of UEs who satisfy the condition to become CoMP users. The CoMP condition can be seen as follows:

$$RSRP_{CRP\ cell} > RSRP_{serving} - CoMPMargin_{dB}$$

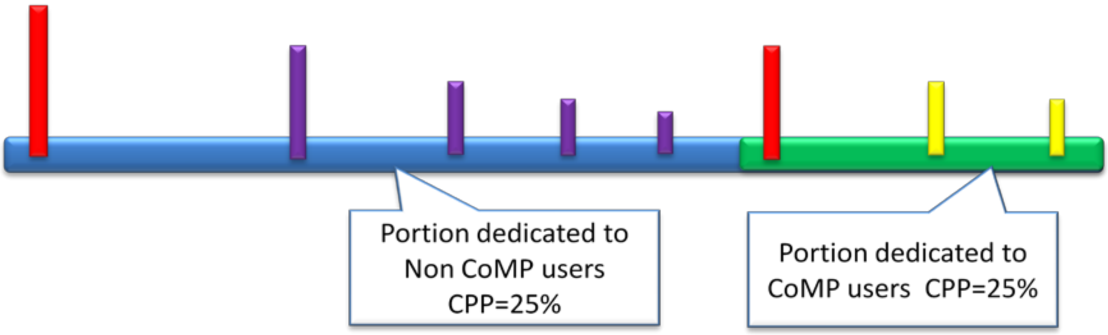
Cell selection for every UE aims at maximizing RSRP, although a constant bias (Selectable Value) is added to the nominal small cell RSRP. This procedure, known as Cell Range Expansion (CRE), helps compensating for the power gap between macro and small cells, thus offloading UEs from the former to the latter. The CRE power bias is applied to both service cell selections as well as to the selection of Coordinated Reception Points for CoMP. In order to reduce the complexity of the simulation, the CRE bias at all small-cell eNBs are equal and static during the simulation.

Our simulation is based on different values of CoMP margin. Instead of changing the number of CoMP users or alternatively changing the cell edge width, we decide to observe the effect of various CoMP margin deployments in the simulation.



CoMP Pool Percentage-CPP

This parameter defines the portion of the resources which should be allocated to user connecting to eNB as a CRP cell for each eNB. CPP value for each eNB is variable during the simulation. The aim of article if suggest a solution to better select a value of CPP. In our algorithm CPP value is indeed based on the number of physical resource blocks reserves as frequency resources for CRP users. Lowest value of CPP is equal to 0 percent and maximum possible value is 50 percent. It is needed to mention that the in case of absence of users connection to a particular eNB as Serving or CRP , CPP value for that particular eNB set to 100% and 0% respectively.



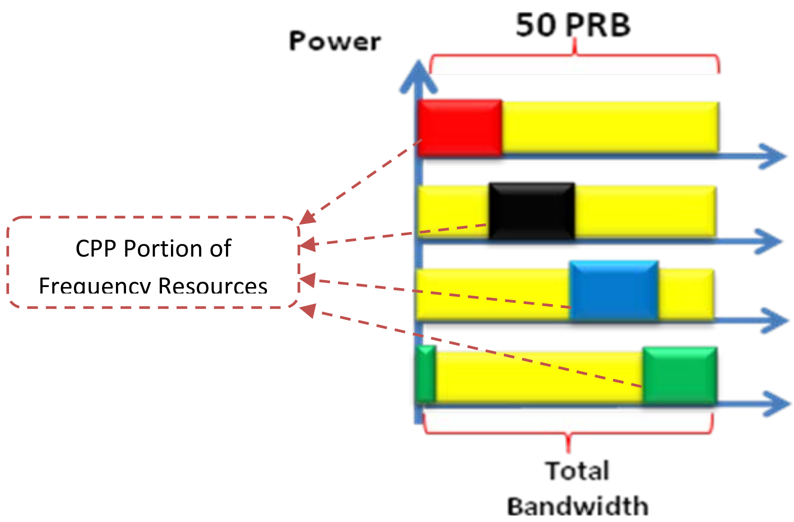
In order to better optimize the resources we define a CPP value to easily allocate the resources for CoMP and non-CoMP users. Itemize properties of CPP are listed as follows:

- Portion of the resources allocated to a user connecting to eNB as a CRP cell for each eNB
- CPP value for each eNB is variable during the simulation
- Based on the number of physical resource blocks
- CPP portion is managed according Frequency Reuse
- In case of absence of CoMP or Non-CoMP users, CPP can be set to 0 or 100%
- Suggest a solution to better select a value of CPP.

Frequency Reuse

Frequency Reuse is a well known concept that has been applied to wireless systems over the past two decades e.g. in GSM systems. As the name suggests Frequency Reuse implies using the same frequencies over different geographical areas. if we want to increase the number of users we would have to reuse the same frequency band in a geographically separated area. The technique usually adopted is to use a fraction of the total frequency band in each cell such that no two neighbor cells use the same frequency. In our set of simulation we use frequency reuse of 4^{th} factor. In Soft Frequency Reuse (SFR) the cell area is divided into two regions; a central region where the entire frequency band is available and a cell edge area where only a small fraction of the spectrum is available. The spectrum dedicated for the cell edge may also be used in the central region if it is not being used at the cell edge. The lack of spectrum at the cell edge may result in much reduced Shannon Capacity for that region. This is overcome by allocating high power carriers to the users in this region thus improving the SINR and the Shannon Capacity.

- ✓ eNBs are using the whole spectrum (10 or 20 MHz)
- ✓ Adjacent eNBs are using different Spectrum band (CPP portion) for their CoMP users (cell edge users)
- ✓ Frequency Reuse Factor of 4
- ✓ Cells with sufficiently large distance can use the same frequency band.



Resource allocation and throughput computation

Our performance evaluation focuses on the allocation of radio resources among CoMP and non-CoMP users. At a system level, we assume that frequencies are allocated to eNBs according to the Fractional Frequency Planning, with a frequency reuse factor of 4. We use a co-channel frequency deployment; hence small cells use the same frequency band that macro cells use. Our algorithm model clearly accounts, through equation below for any possible interference among users in different cells, who are allocated the same PRBs.

$$SINR = \frac{P_{RX}(PRB)}{P_{noise} + \sum_{u \in S} P_{RX}(u)}$$

Where S is a set of UEs, which the same PRB is dedicated to them for their uplink communication.

Within a cell, we simulate different resource splits. Every cell sets aside a fraction of resources, i.e., of Physical Resource Blocks (PRBs), for UEs that transmit to it as their serving cell. These resources are typically allocated to UEs close to the cell core. The remaining fraction of PRBs is reserved for UEs that use the cell as CRP and are thus close to the edge. We identify the latter fraction, i.e., the portion of PRBs that are reserved for CoMP as CoMP Pool Percentage (CPP). In each instance, the value of CPP is identical across all cells in whole network or cluster involved in CoMP (which, as we have seen, depends on the scenario). By definition, CPP is 0 for cells that do not participate in CoMP. We also point out that if the CPP of a cell is not completely allocated for lack of CoMP users, its PRBs are available to be scheduled for non-CoMP users.

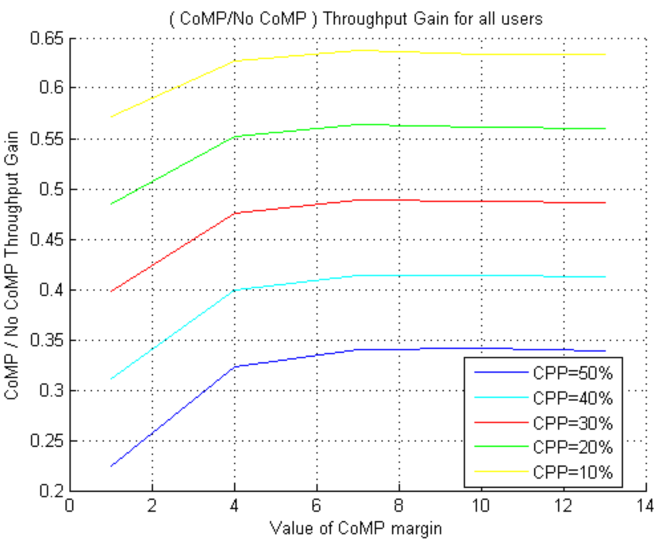
Resources are then allocated to UE for their uplink communication based on the Proportional Fair (PF) scheduling policy. The PF policy combines high throughput proportional fairness among all UEs by giving instantaneous priority to UEs with a high-quality channel rate and a low average service rate. The user uplink throughput is computed (by Shannon formula) from the number of PRBs that the scheduler allocates to each user, depending on the cell it communicates with (either serving or CRP) and the associated SINR calculated above. It should be mentioned that the effect of fast fading is also considered in the obtained results.

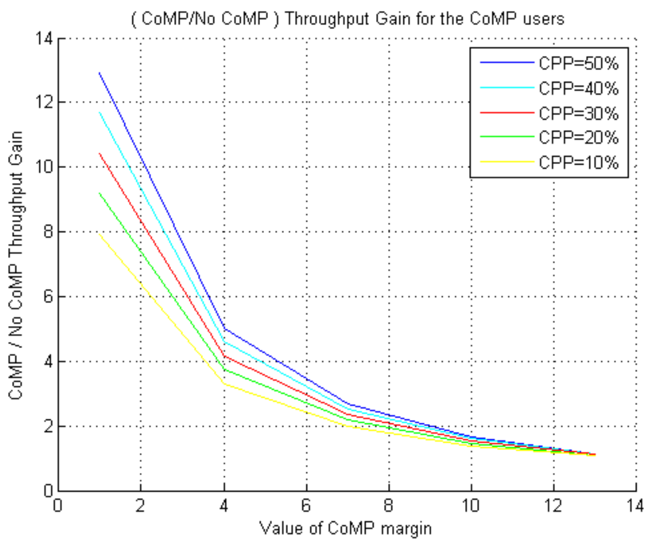
Simulation and Results

After what we have seen in chapter 1, we decide to deploy a fixed number of Macro cells of 15 and variable number of small cell to proceed with other functionalities of the heterogeneous cellular network.

Simulation in this chapter aims to show the gain of using CoMP over not using CoMP in mentioned cellular network. Mentioned in previous pages, some properties are added to the cellular network and specially scheduling algorithm.

- Different deployment of heterogeneous network, likewise deployment if 15, 25, 50 and 75 small cells
- Apply different value of fixed CPP (10%,20%,30%,40%,..)
- Use of different CoMP scenarios (Intra, Inter, Small, Het)
- Different scheduling algorithms (proportional fairness and Round Robin)
- Observe the response of the network in term of throughput for different CoMP margins (1,4,7,10, 13 dB)
- Evaluate the results for “All users” and just “ CoMP users”

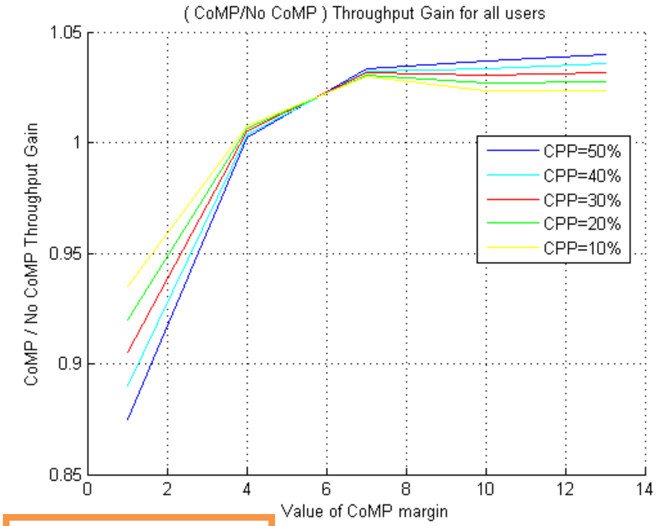


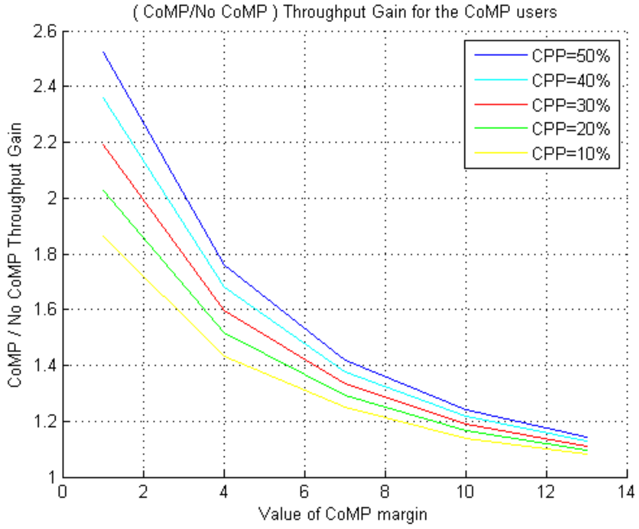


Macro cell number = 15, Small cell number= 15, Round Robin scheduling

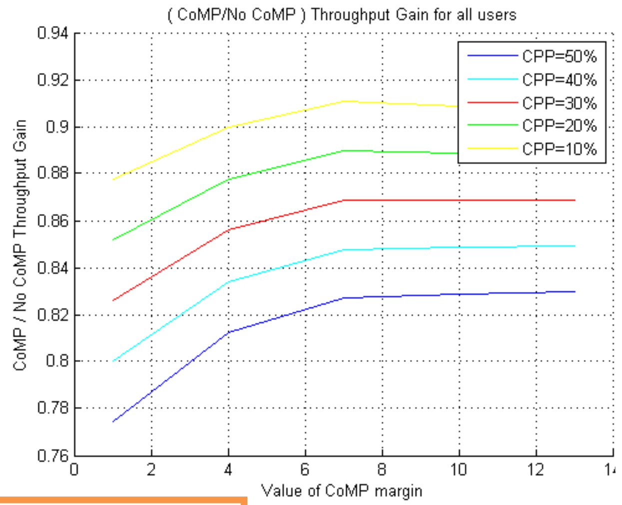
Small Scenario

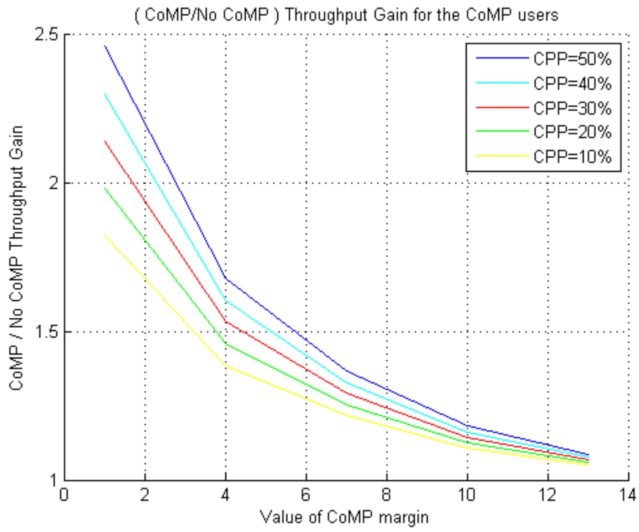
Macro cell number = 15, Small cell number= 15, Round Robin scheduling



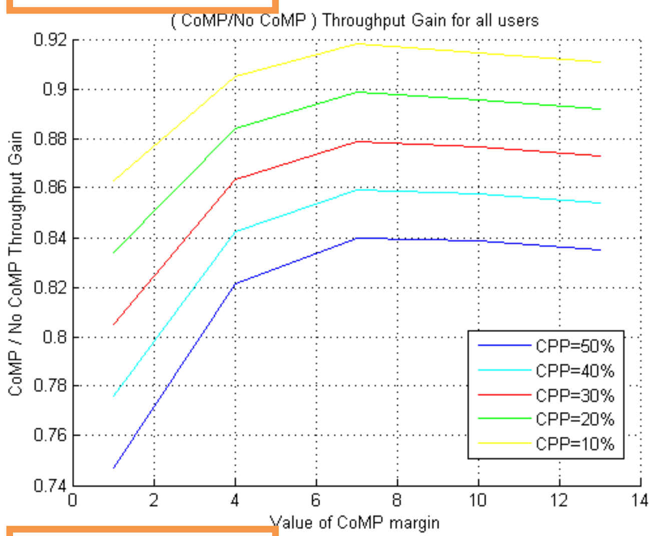


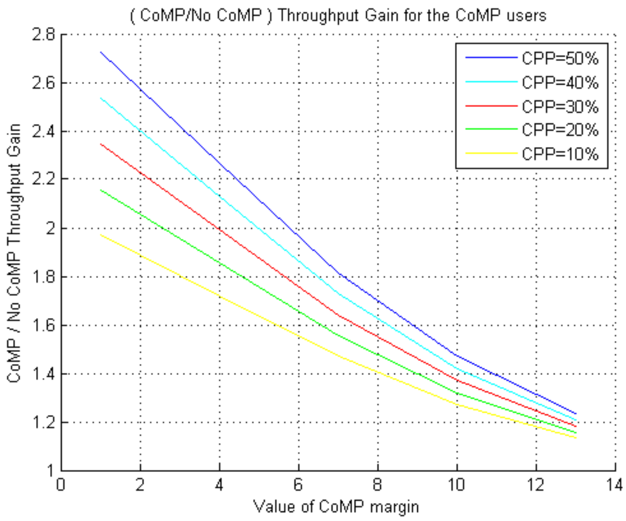
Het scenario





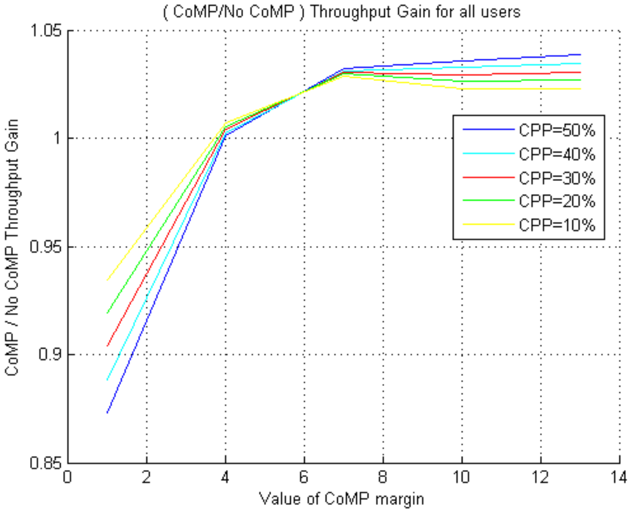
Intra scenario

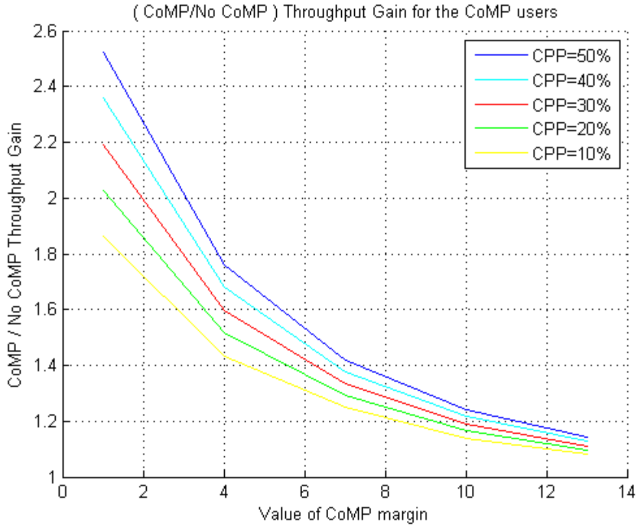




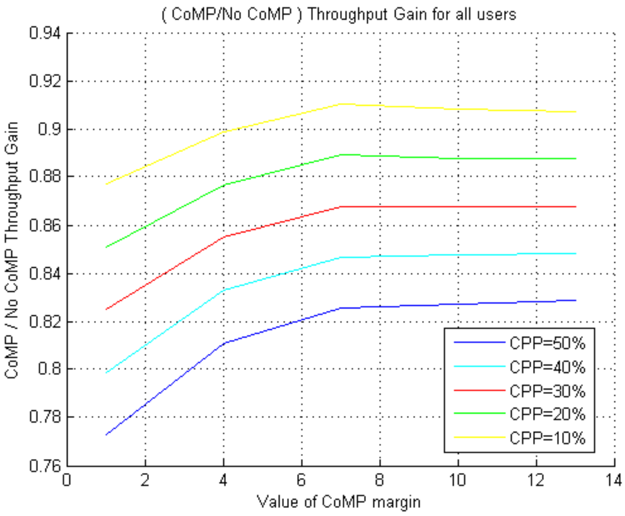
Inter scenario

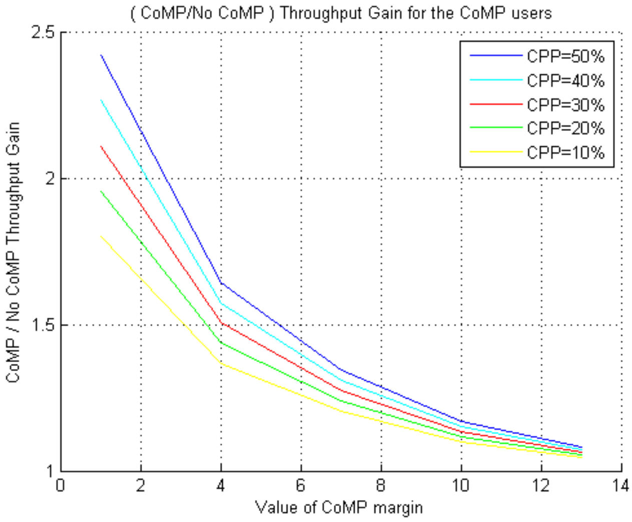
Macro cell number = 15, Small cell number= 15,P.F scheduling



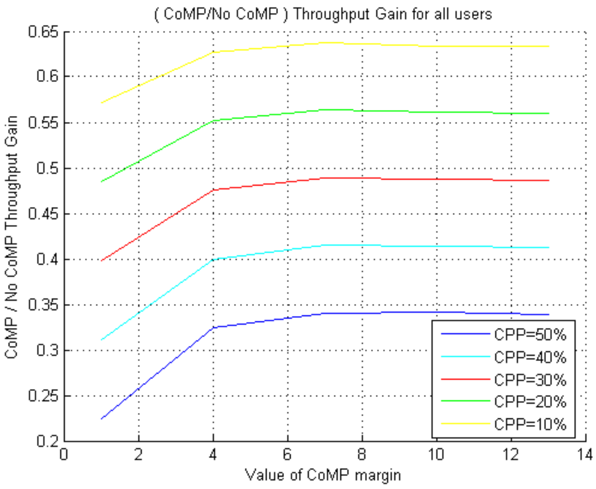


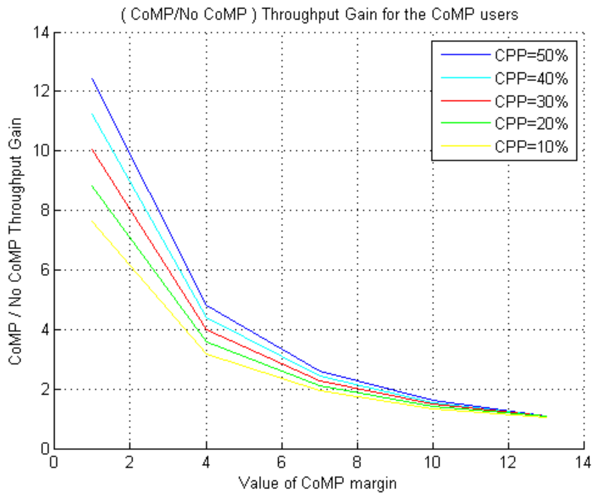
Het scenario



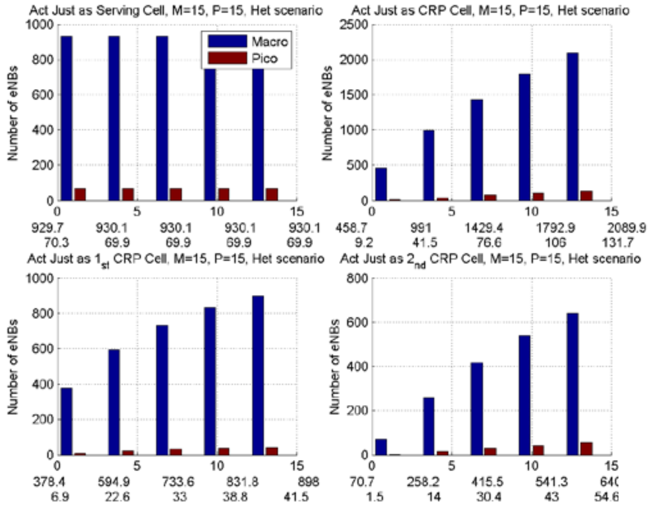


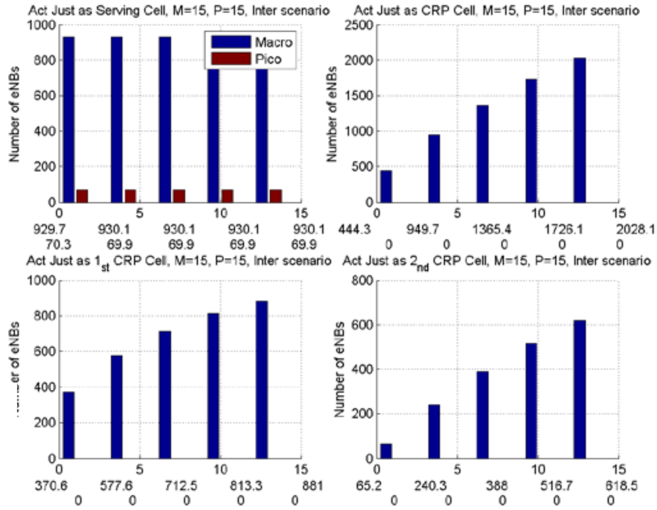
Intra scenario

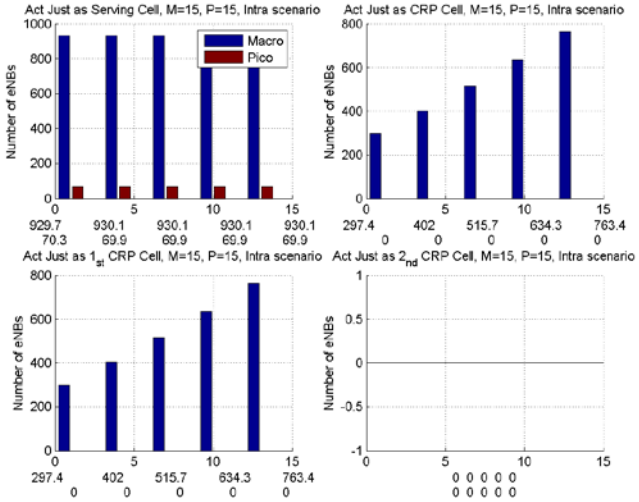


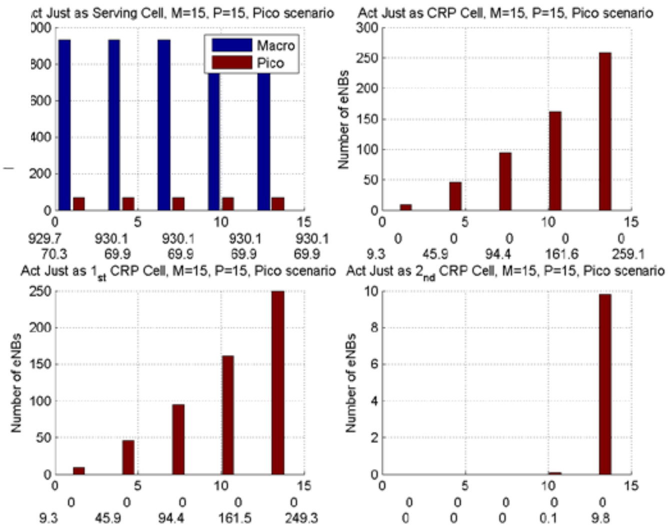


Connection Statistics

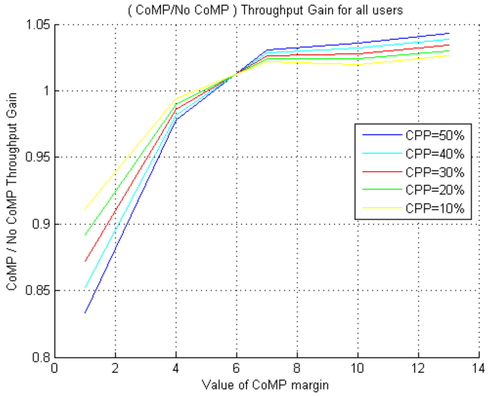


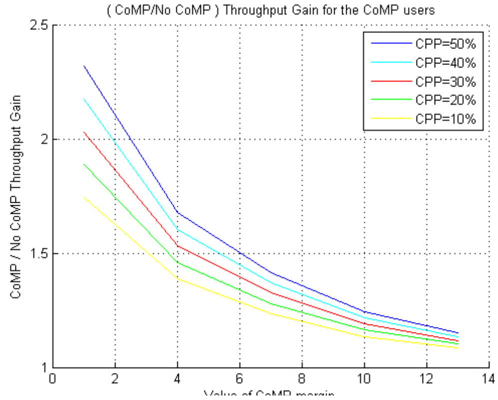




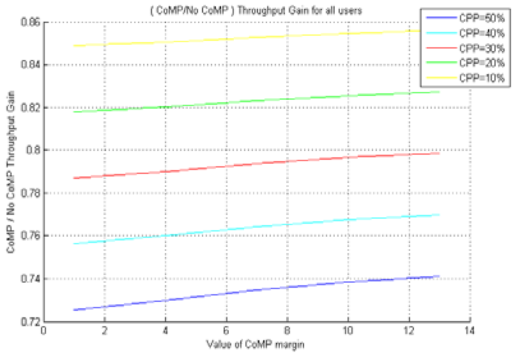


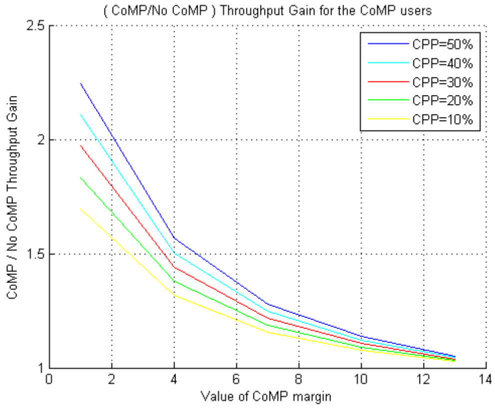
Macro cell number = 15, Small cell number= 25,R.R scheduling



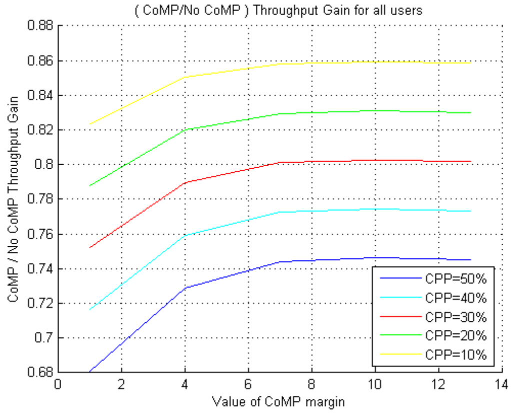


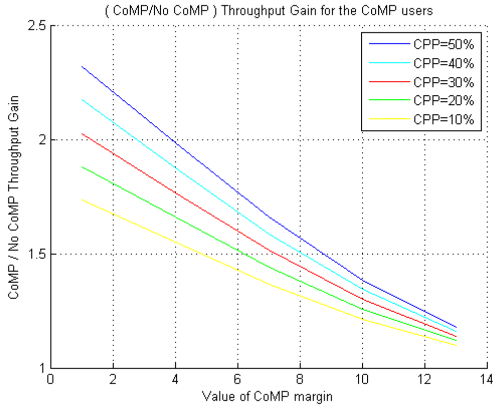
Het scenario



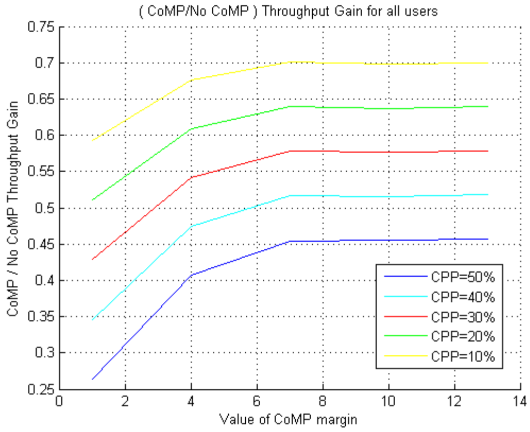


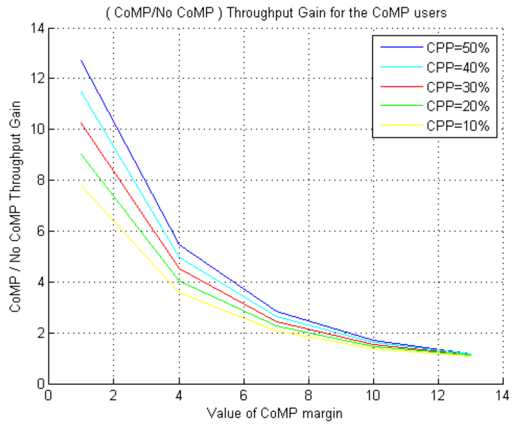
Inter scenario





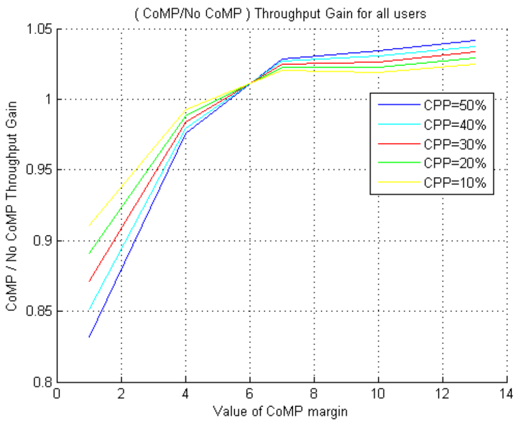
Intra scenario

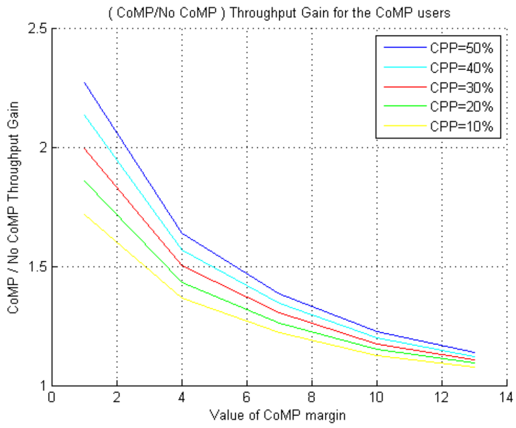




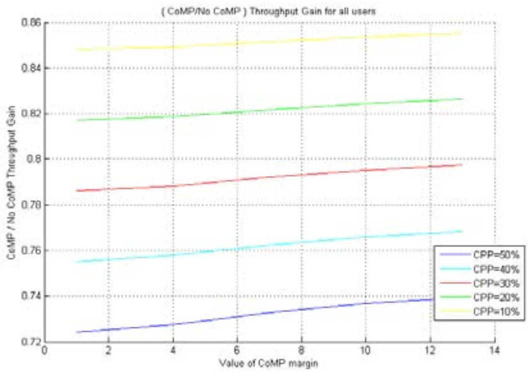
Small scenario

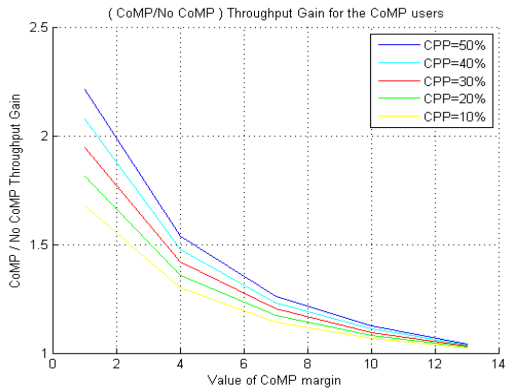
Macro cell number = 15, Small cell number= 25,P.F scheduling



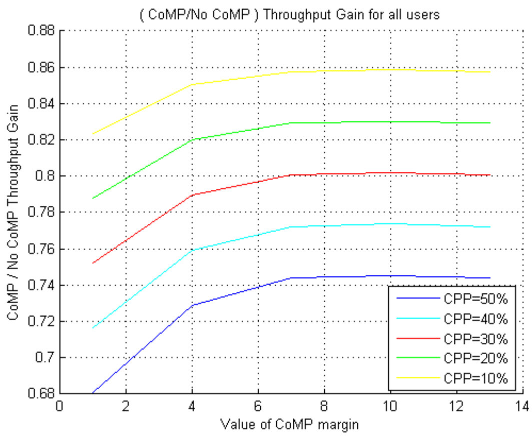


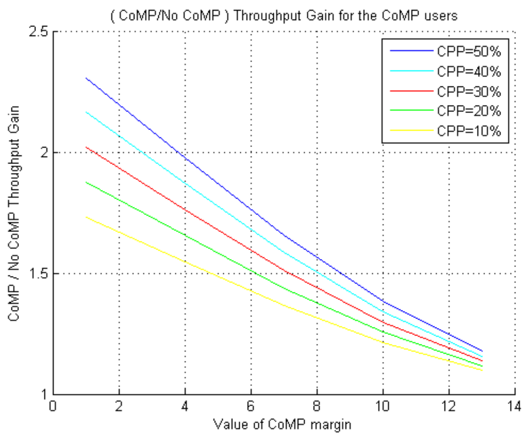
Het scenario



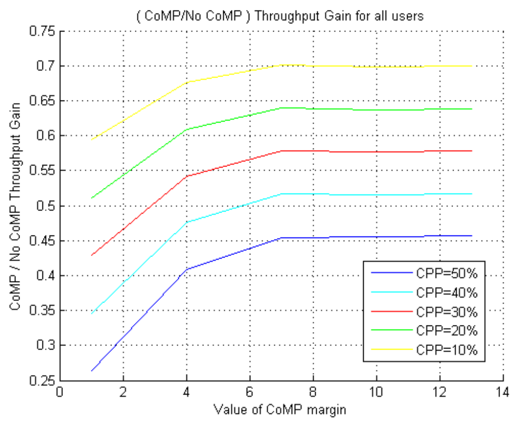


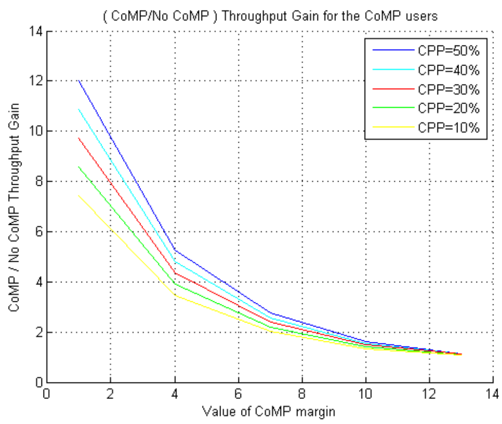
Inter scenario





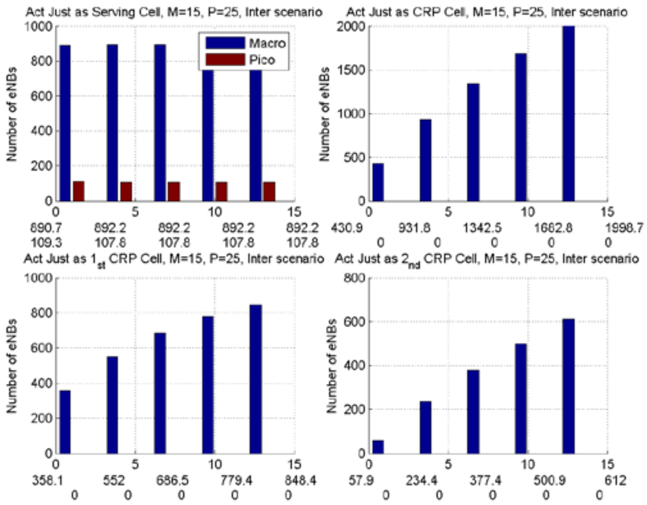
Intra scenario

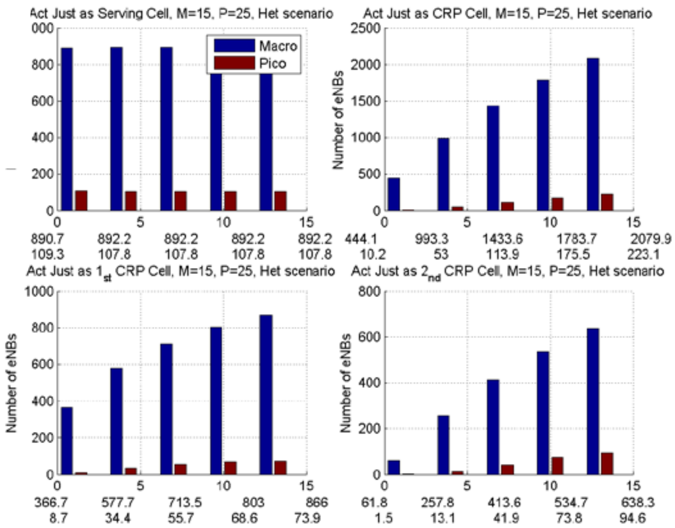


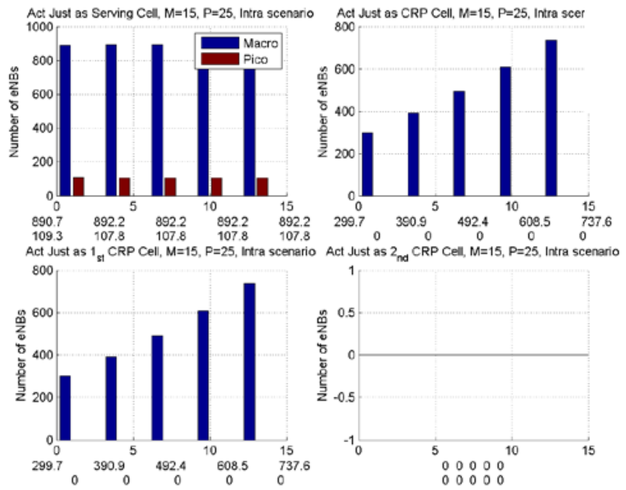


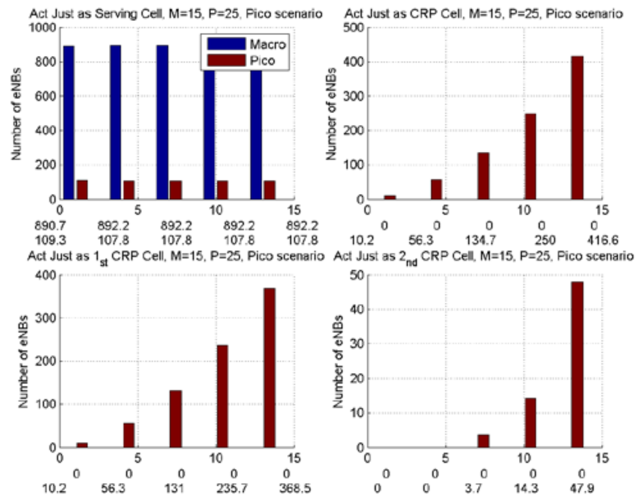
Small scenario

Connection Statistic

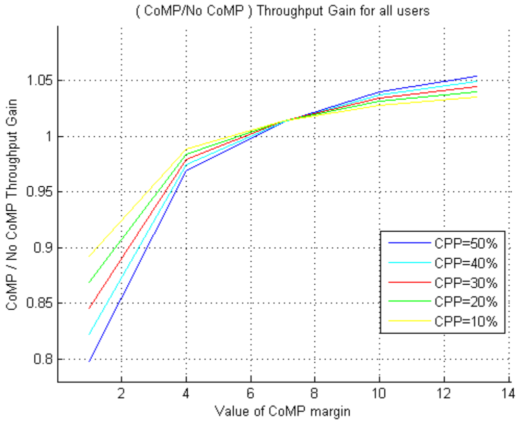


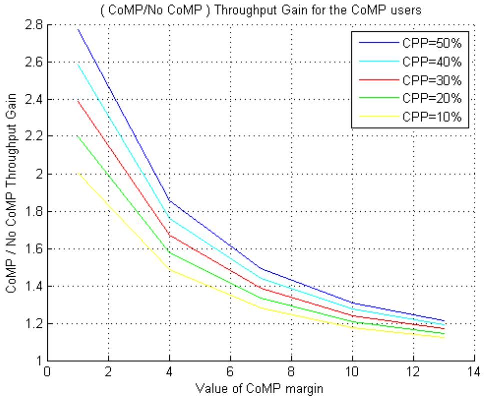




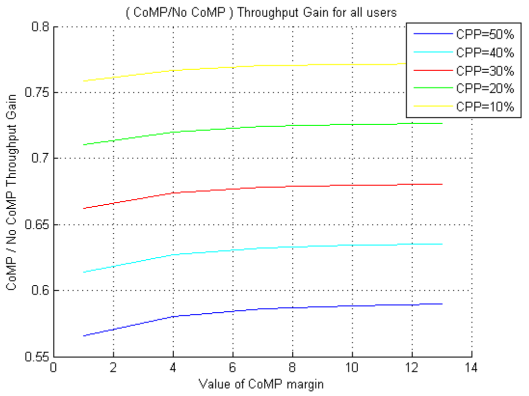


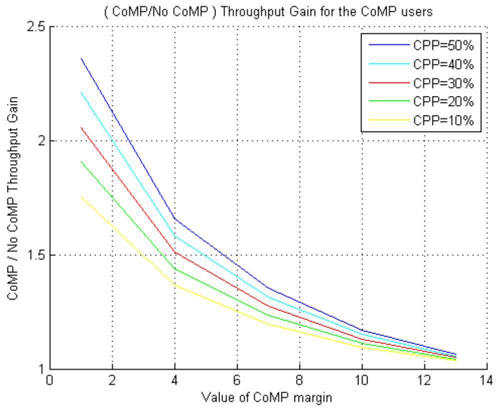
Macro cell number = 15, Small cell number=50,R.R scheduling



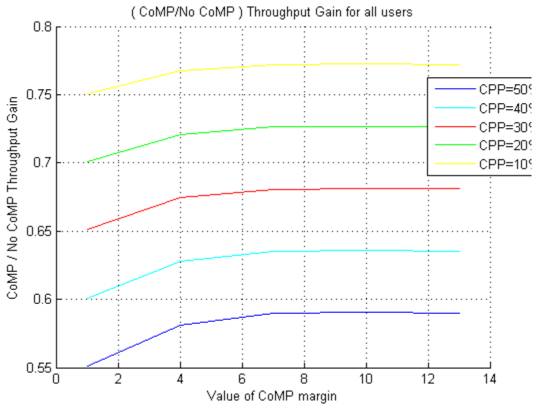


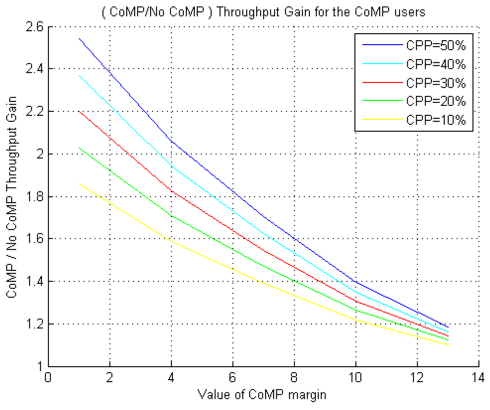
Het scenario



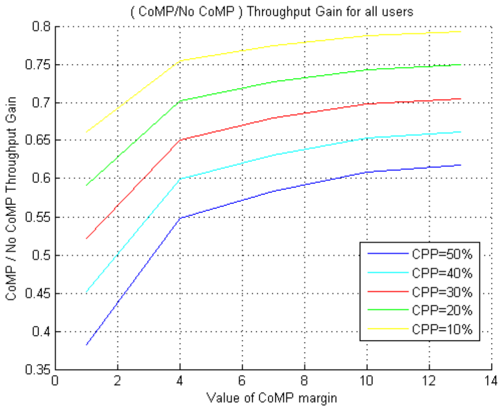


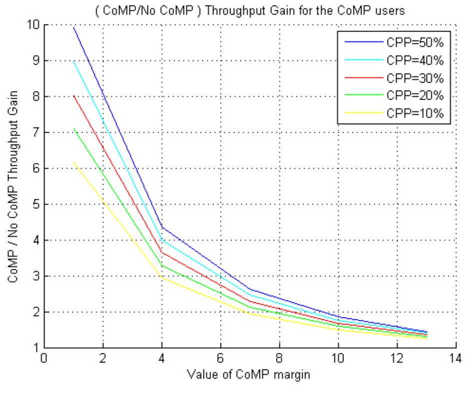
Inter scenario





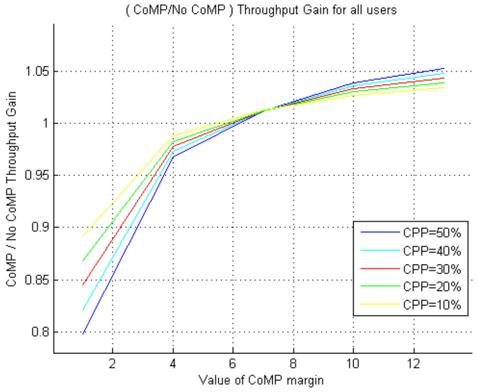
Intra scenario

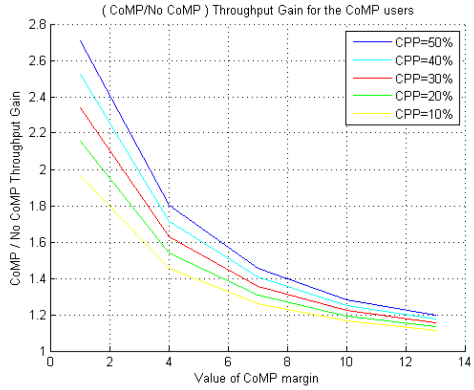




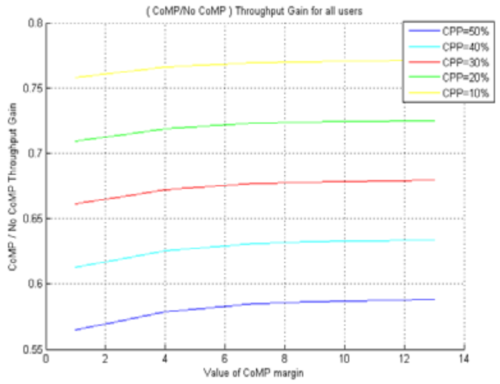
Small scenario

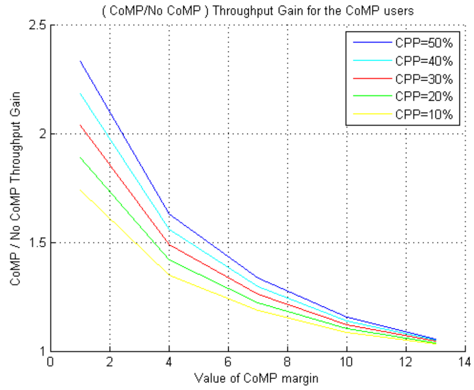
Macro cell number = 15, Small cell number=50, P.F scheduling



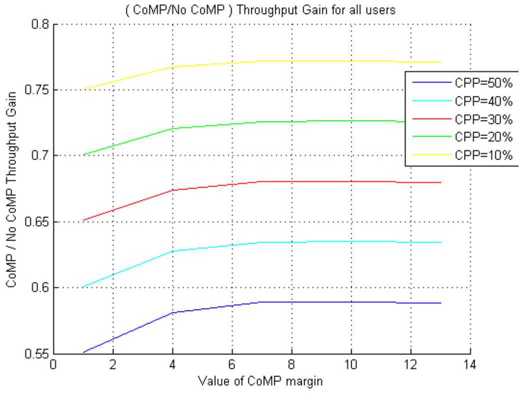


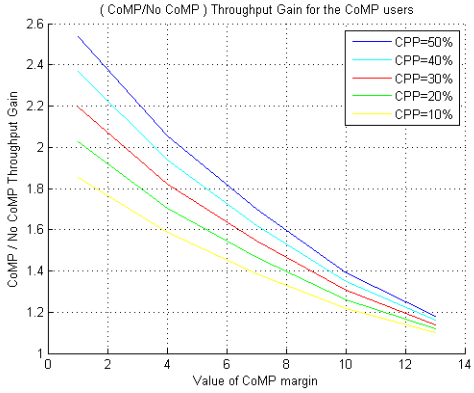
Het scenario



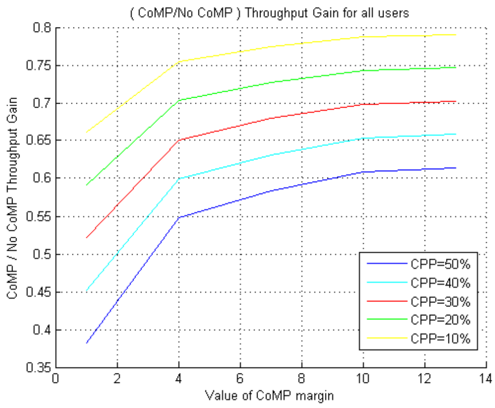


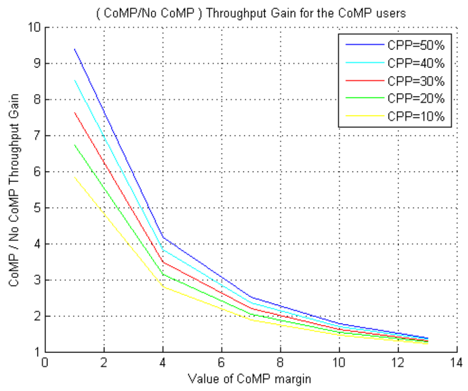
Inter scenario





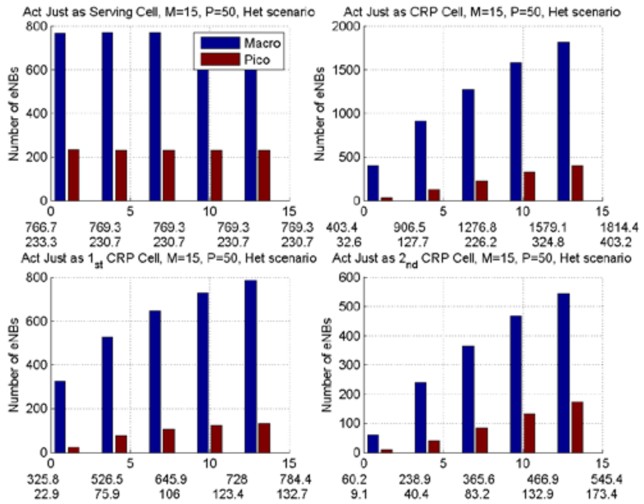
Intra scenario

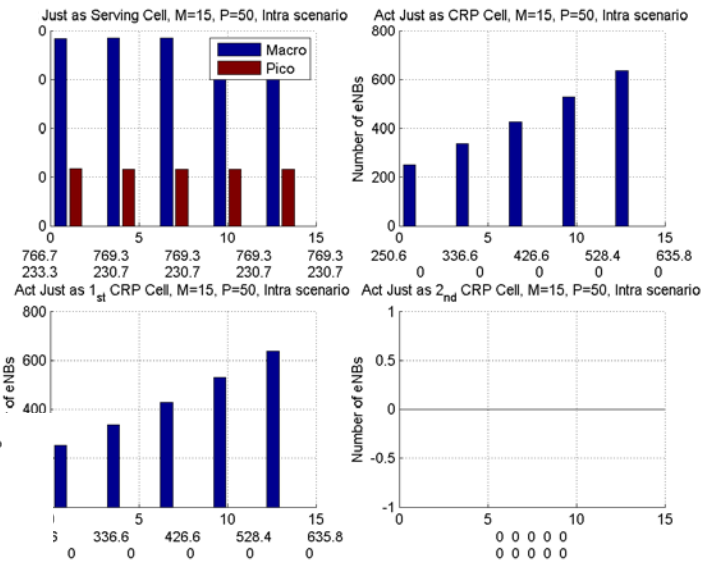


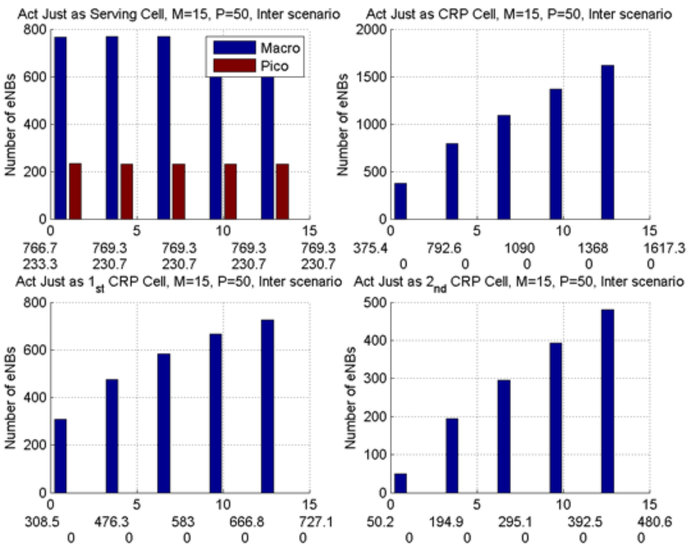


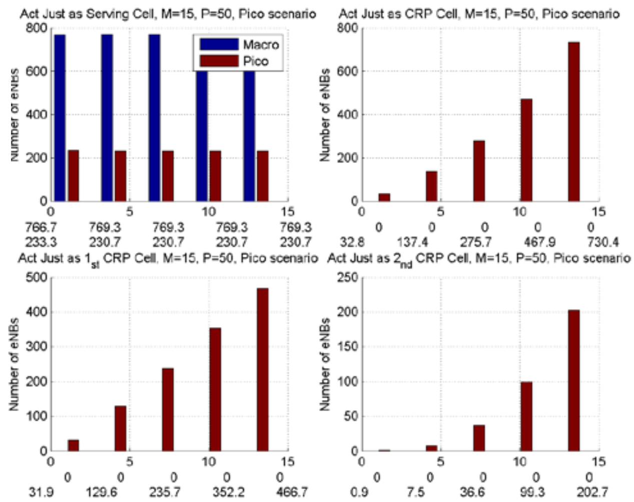
Small scenario

Connection Statistics

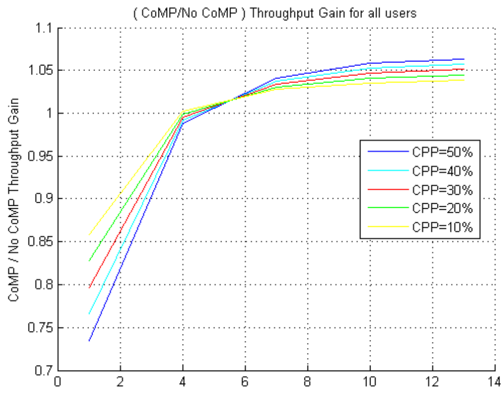


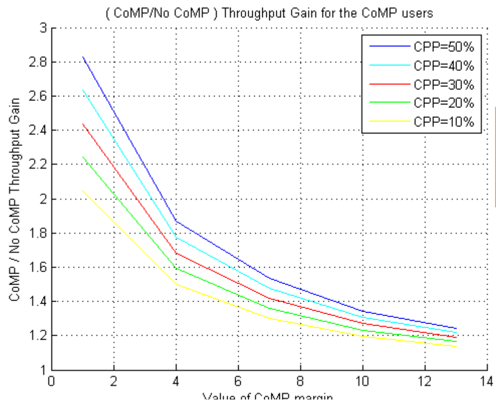




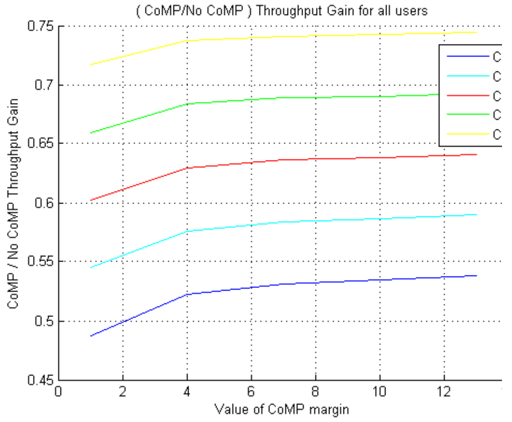


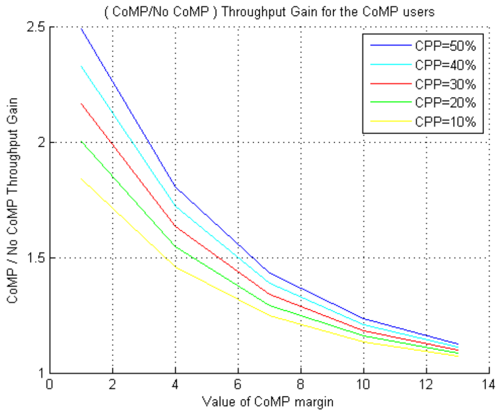
Macro cell number = 15, Small cell number=75, R.R scheduling



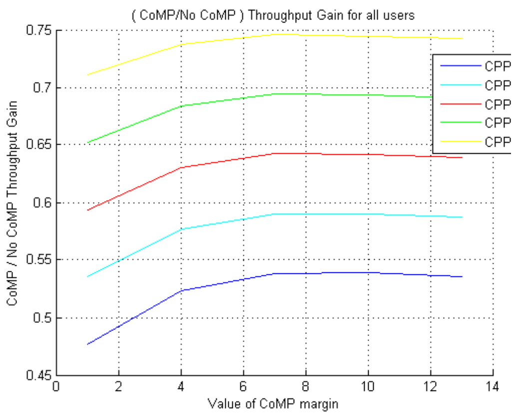


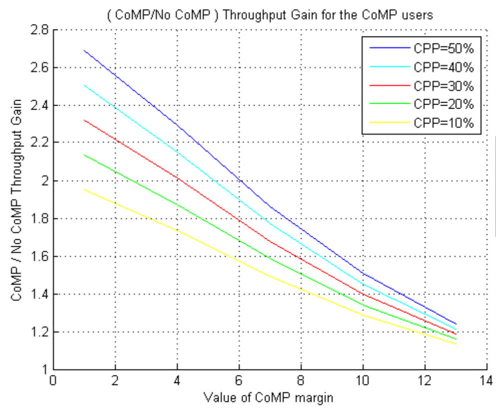
Het scenario



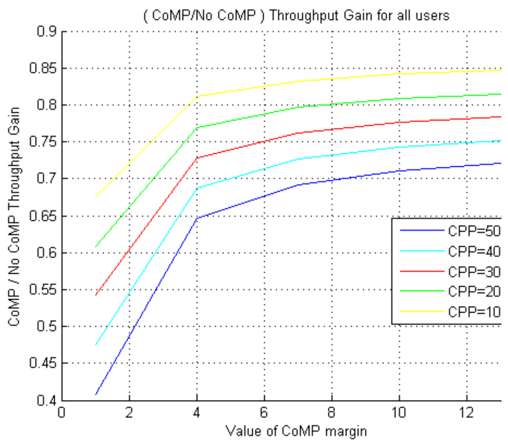


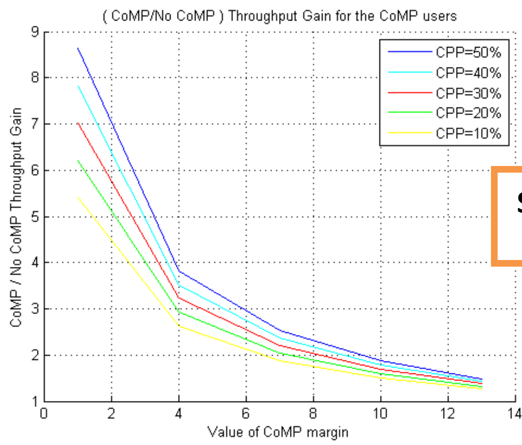
Inter scenario





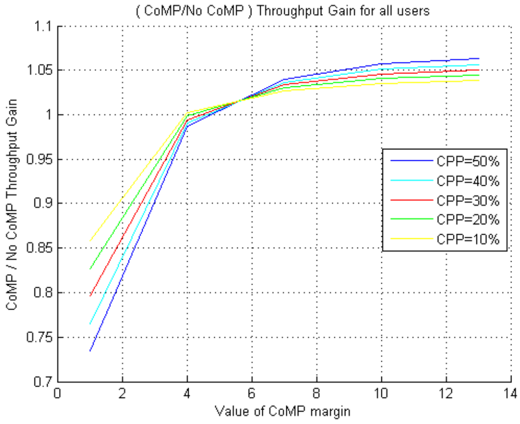
Intra scenario

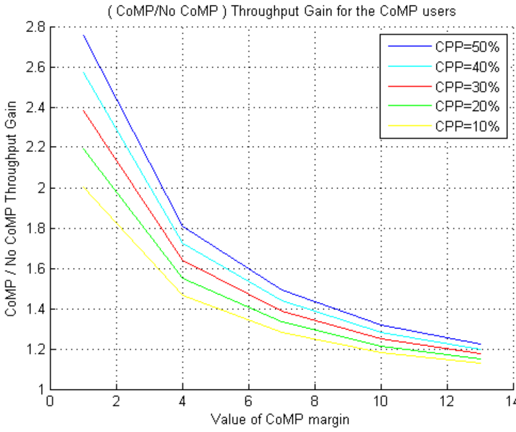




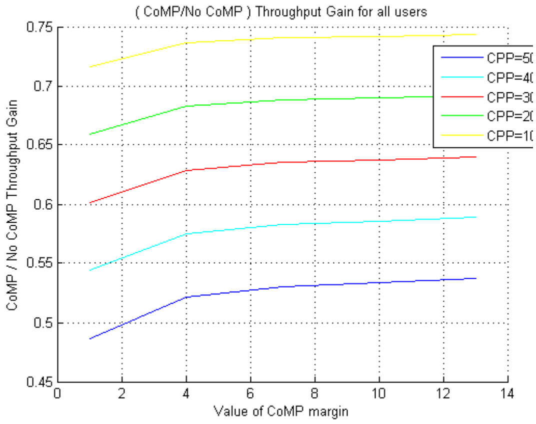
Small scenario

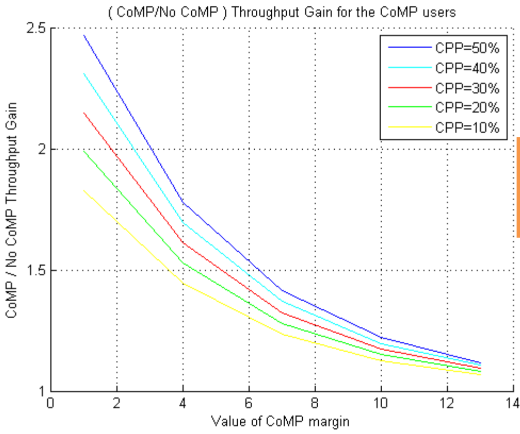
Macro cell number = 15, Small cell number=75,P.F scheduling



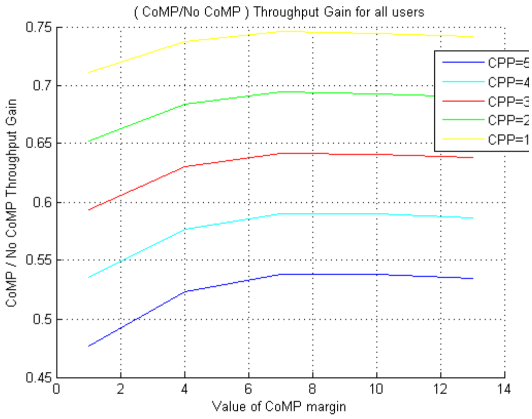


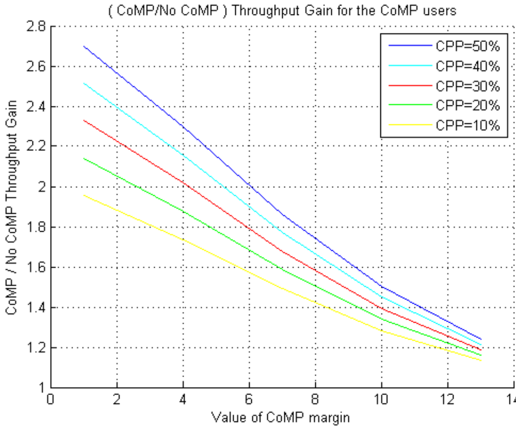
Het scenario



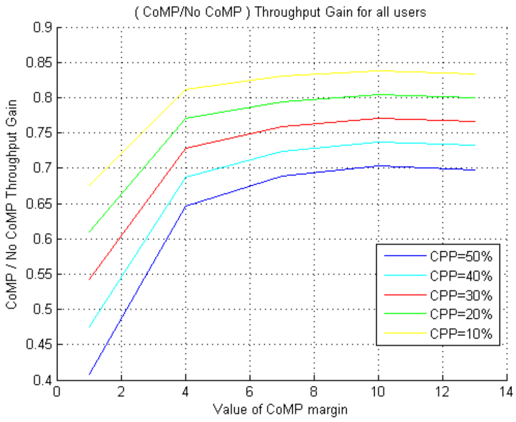


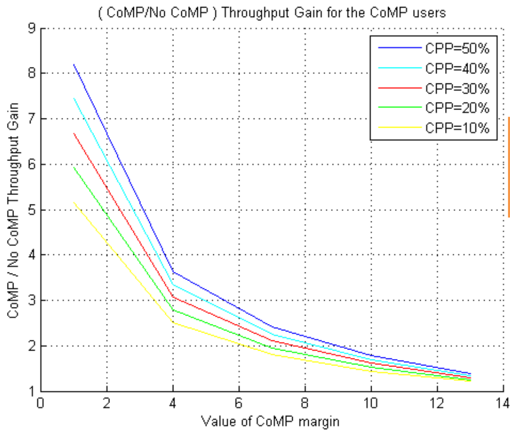
Inter scenario





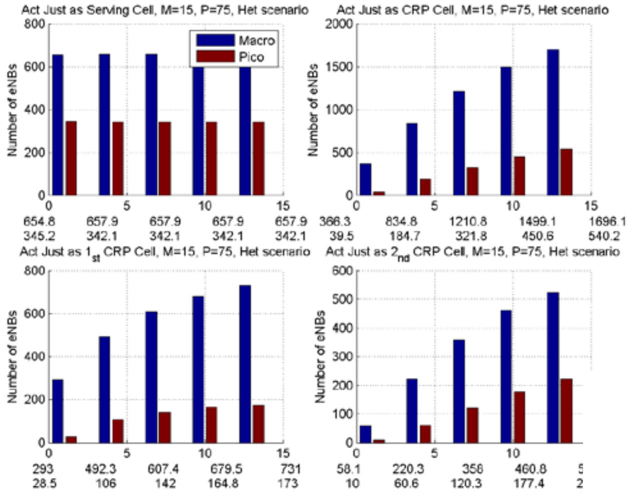
Intra scenario

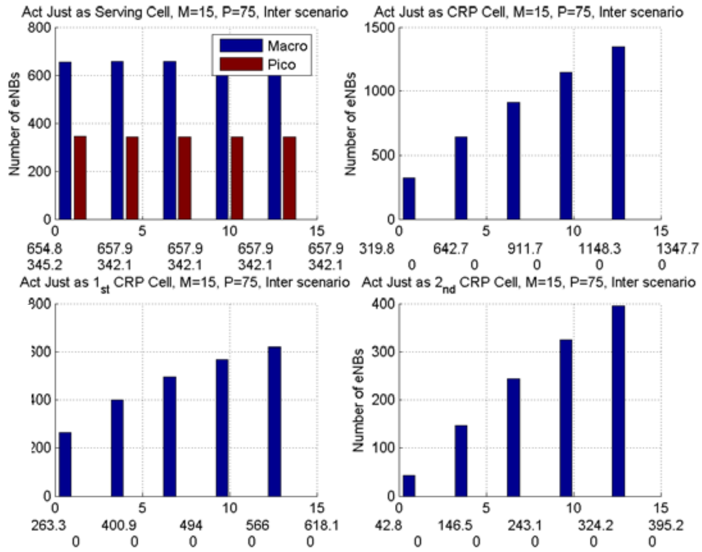


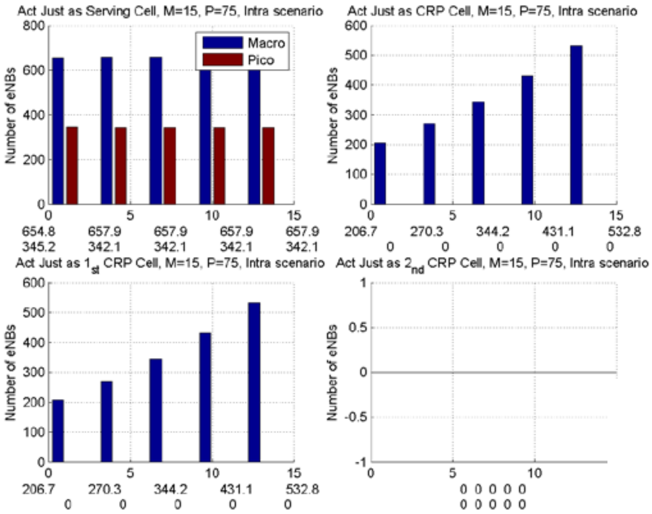


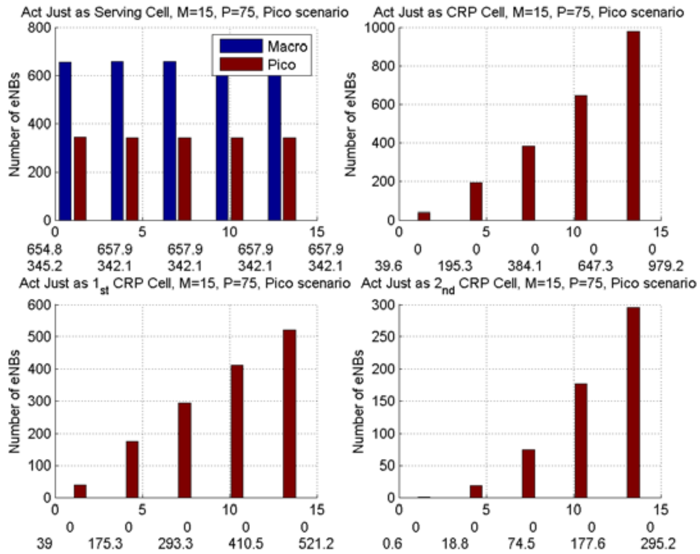
Small scenario

Connection Statistics









Chapter 3

Resource allocation and throughput computation

Our performance evaluation focuses on the allocation of radio resources among CoMP and non-CoMP users. At a system level, we assume that frequencies are allocated to eNBs out of a 20-MHz band according to the Fractional Frequency Planning scheme, with a frequency reuse factor of 4. We use a co-channel frequency deployment; hence small cells use the same frequency band that macro cells use. Our simulation model clearly accounts, through equation below, for any possible interference among users in different cells, who are allocated the same PRBs.

Within a cell, we simulate different resource splits. Every cell sets aside a fraction of resources, i.e., of Physical Resource Blocks (PRBs), for UEs that transmit to it as their serving cell. These resources are typically allocated to UEs close to the cell core. The remaining fraction of PRBs is reserved for UEs that use the cell as CRP and are thus close to the edge. We identify the latter fraction, i.e., the portion of PRBs that are reserved for CoMP as CoMP Pool Percentage (CPP). In each simulation instance, the value of CPP is identical across all cells involved in CoMP (which, as we have seen, depends on the scenario). By definition, CPP is 0 for cells that do not participate to CoMP. We also point out that if the CPP of a cell is not completely allocated for lack of CoMP users, its PRBs are available to be scheduled for non-CoMP users.

Resources are then allocated to UE for their uplink communication based on the Proportional Fair (PF) scheduling policy. The PF policy combines high throughput proportional fairness among all UEs by giving instantaneous priority to UEs with a high-quality channel rate and a low average service rate. The user uplink throughput is computed from the number of PRBs that the scheduler allocates to each user, depending on the cell it communicates with (either serving or CRP). The throughput yielded by each PRB is derived from Shannon's formula, assuming a bandwidth of 180 kHz per PRB, a noise power of -174 dBm/Hz, and a SINR computed as:

$$SINR = \frac{P_{RX}(PRB)}{P_{noise} + \sum_{u \in S} P_{RX}(u)}$$

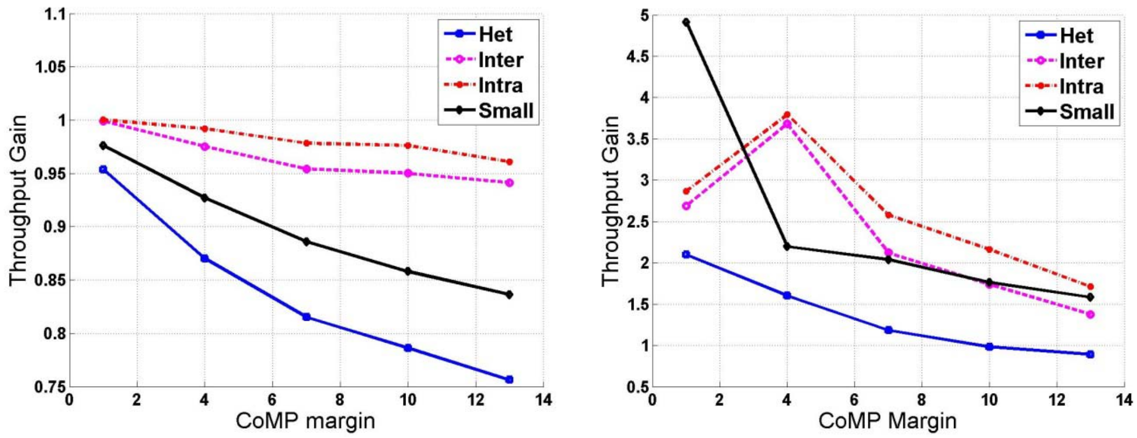
where S is a set of UEs, which are allocated the same PRB for their uplink communication.

UEs are assumed to be in saturation, i.e., they always have data traffic to upload and greedily use all the resources they are allocated by the eNB.

Fixed CPP Algorithm

Simulations were run on a system-level simulator written in MATLAB and conformant to LTE specification. The time granularity of the simulation is one second, thus the throughput is computed every second. Every simulation run lasts 60 seconds and results are averaged over 10 different runs.

The first set of results shows the average uplink throughput gain, computed as the ratio between the uplink throughputs achieved when CoMP is active and the uplink throughput achieved when the CoMP functionality is disabled.
We selected a setting with CPP=30% and we tested the four scenarios listed in the previous section. The plot in Figure below shows the uplink throughput gain for all users in the system: as expected, CoMP results in an overall decrease of system throughput, especially for high CoMP margin.



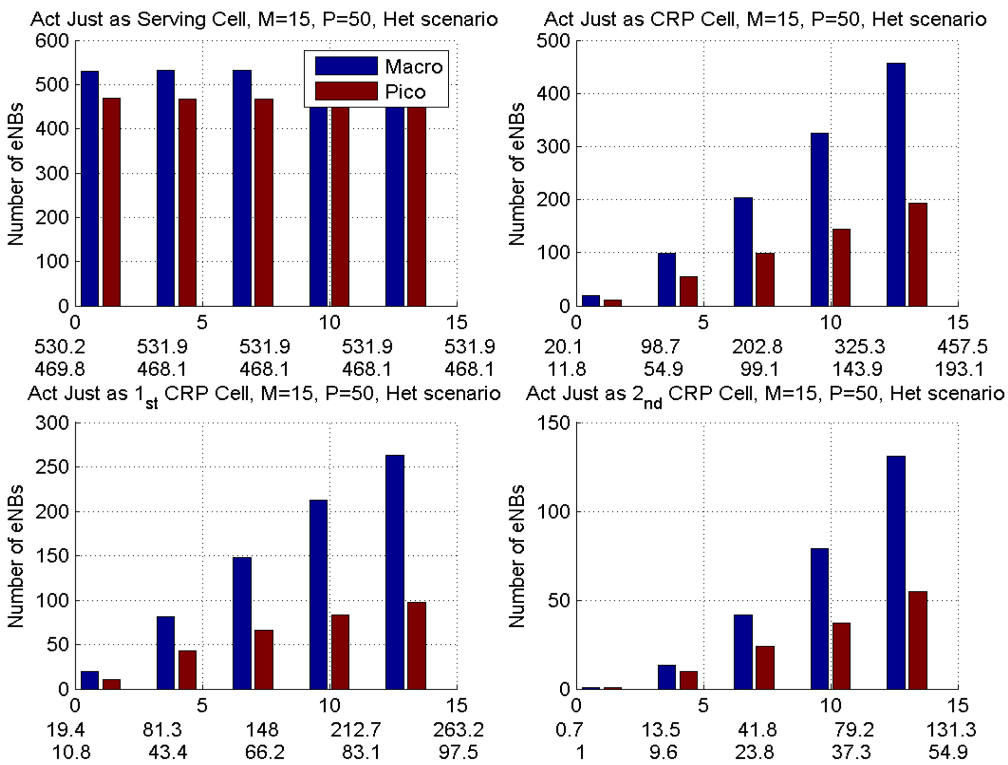
All users | CoMP users

To wit, if the CoMP margin is low, few users end up using CoMP, and the throughput of UEs in the center of the cell (who are unlikely to be candidates for CoMP) is unaffected, tipping the balance toward smaller throughput decrease. Recall, indeed, that CPP resources are preempted by CoMP users, but are scheduled for non-CoMP users if they go unclaimed due to the lack of potential CoMP users. Instead, for higher values of the CoMP margin, the overall throughput is smaller, especially for the Het scenario (blue curve), where losses in excess of 20% are recorded. The reason for such a poor performance is to be sought in the non-optimized resource split among macro and small cells and in the specific user distribution in our scenario. Indeed, having many users clustered around small cells (hotspots) should call for different CPP for the two types of cells: specifically, a lower CPP for small cells (because they are serving cells for a large number of users and thus need the resources for them) than for macro cells. Restricting CoMP to small cells (black curve) does not improve the burden for small cells, but at least frees resources for macro cells, which can thus provide higher throughput when offering ``umbrella" coverage to users that cannot access CoMP.

The Inter and Intra scenarios, leaving small-cell resources untouched, do not feature such a dramatic throughput loss.

While these results may appear to hardly justify the use of CoMP, a different picture is painted by the right side plot of figure above, showing the gain for those users only who actively use CoMP. The situation compared to the previous plot is complementary: when the CoMP margin is small, few users can use CoMP, but they have uncontested access to a large set of resources set aside for them.

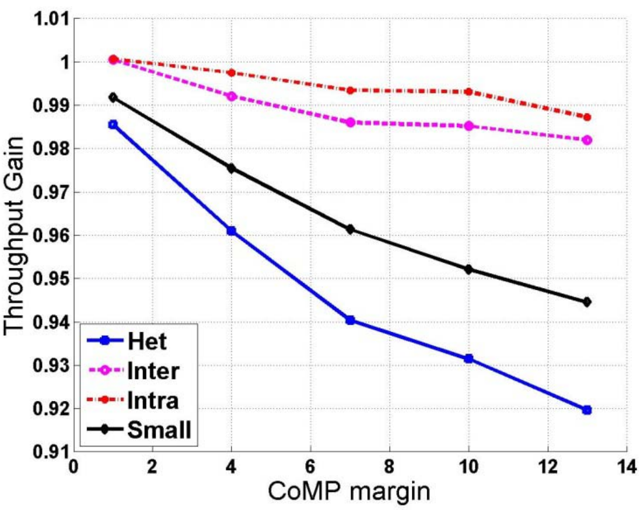
In order to further investigate the remarkable gains of CoMP users in the Inter and Intra scenario, we have looked at the number of users that are involved in each scenario. In the results discussed above, the number of UEs that were connected to a macro cell as their serving cell was 510, while 490 UEs were served by a small cell. The two values are comparable, regardless of the different coverage of the two cell types, thanks to UEs clustering around hotspots served by small cells. We also remark that these numbers of UEs are common to all four scenarios, because the choice of the serving cell is not affected by any of the CoMP policies. We thus need to look at the Het scenario to understand the number of users who select either a macro or a small cell as their CRP cell figure below. As expected, most users select a macro cell due to its larger coverage.



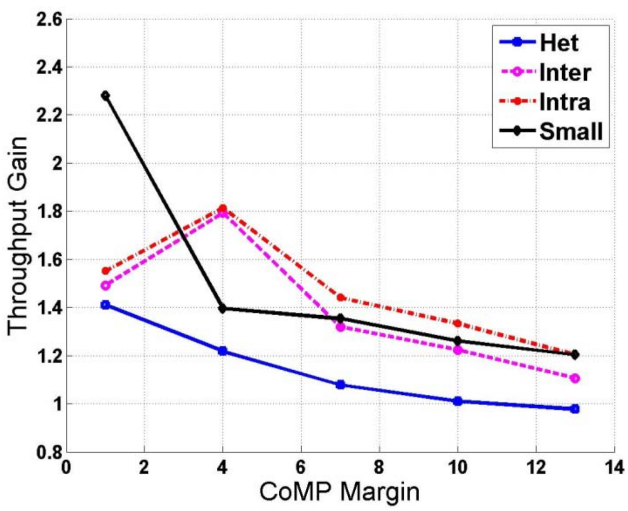
We now turn our attention to the effects of the CoMP Pool Percentage, which are shown in figures depicted in the next page. The top two plots in figure refer to the Het scenario and detail the throughput gain as a function of the CoMP margin, for CPP values ranging from 0% to 50%. In general, the combination of high CoMP margin (which, as we have seen, increases the number of UEs eligible for CoMP) and high CPP negatively affects the throughput of both non-CoMP and CoMP users.

Acceptable values of throughput loss for non-CoMP users, combined with a sizeable gain for CoMP is found for values of CPP around 20%, 30% and low CoMP margin. Similar observations hold for the Small scenario in the other plots of next pages figures.

We highlight an interesting behavior in figure, depicting the Inter (top two plots) and Intra (top two plots) scenarios. For very low CoMP margin (equal to 1 dB, Corresponding to less than 10 CoMP users in either scenario, as show in Figure above, there is practically no overall throughput loss and the gain is remarkable. However, this is due to the limited number of CoMP users, which monopolize the entire CPP resources even when CPP=10%. For margin equal to 4 dB, the number of CoMP users increases (though it is still less than 30) and starts eroding the overall throughput. The gain for CoMP users keeps rising, since CPP resources are still enough to satisfy the limited number of UEs. However, when the margin is higher than 4 dB, the overall throughput inexorably plunges, while the CoMP gain becomes less pronounced. Again, these trends confirm that choosing a small CPP and CoMP margin is the most balanced choice. (Figure below . CPP=10%)

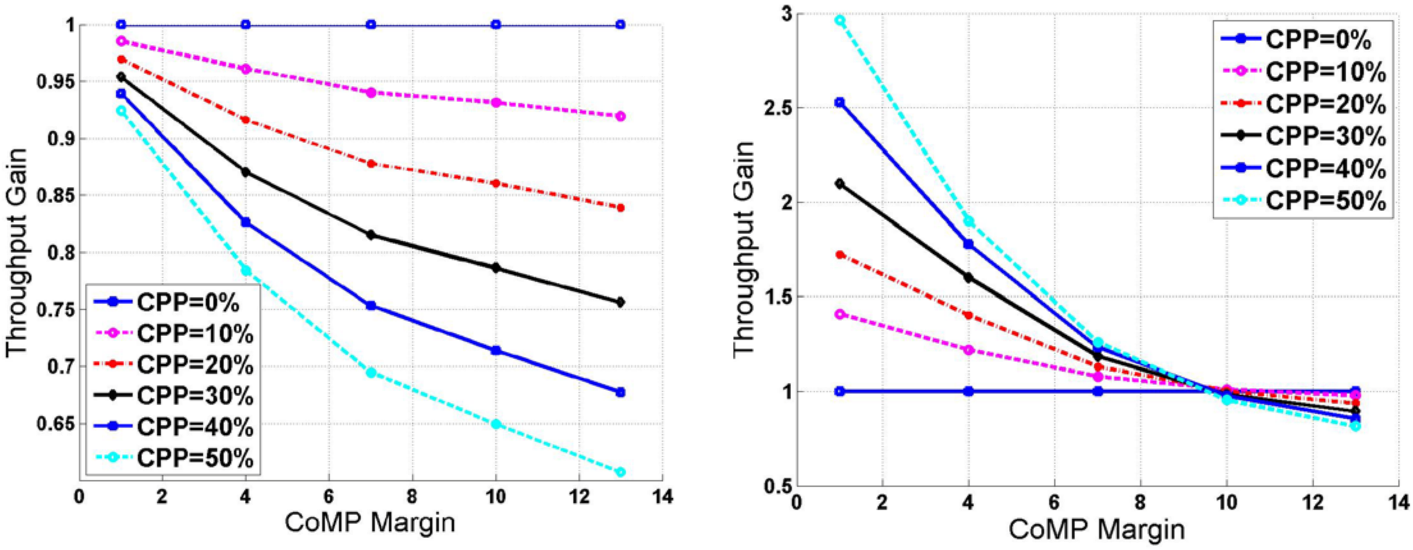


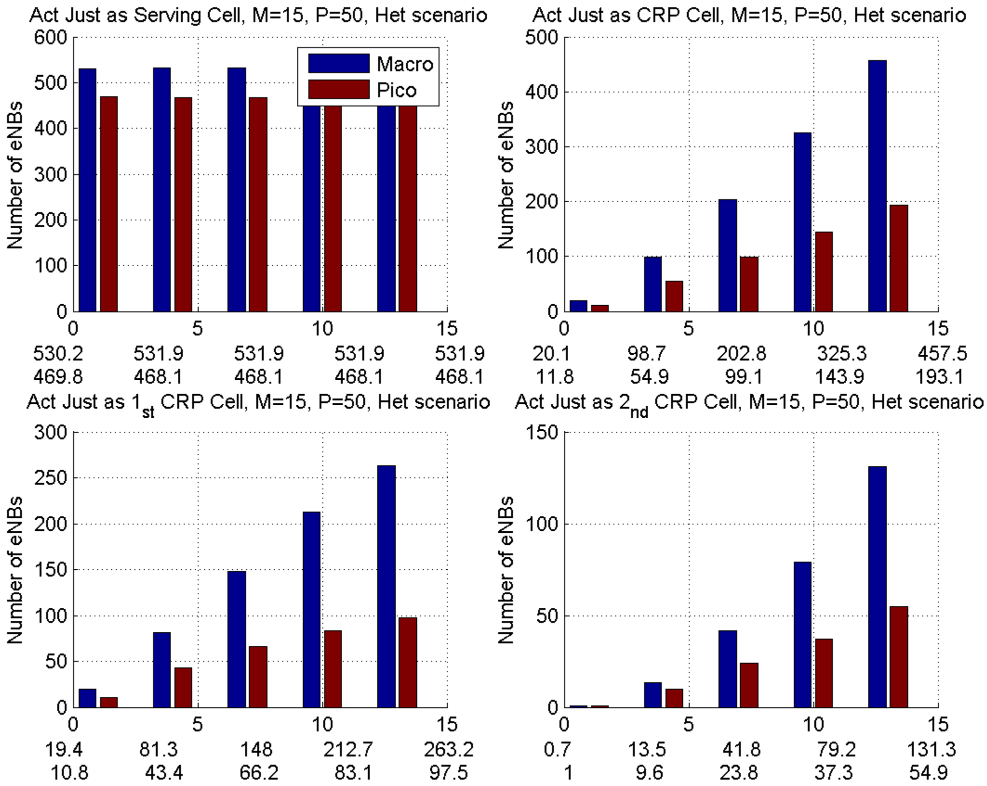
All users



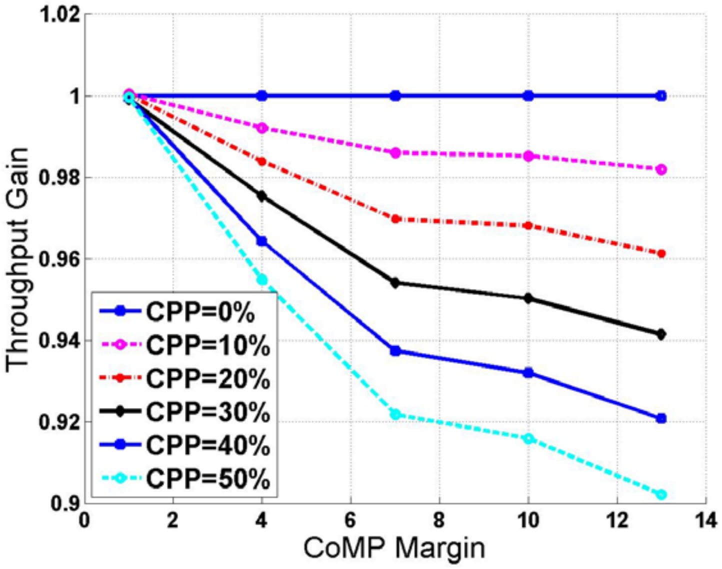
CoMP users

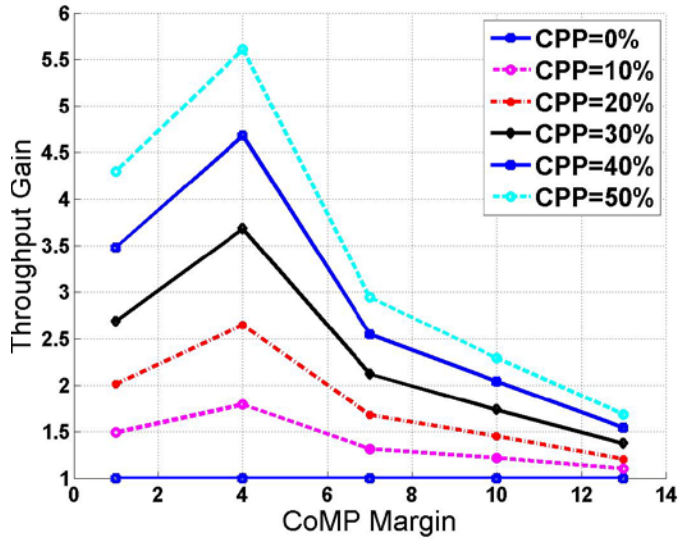
Het Scenario

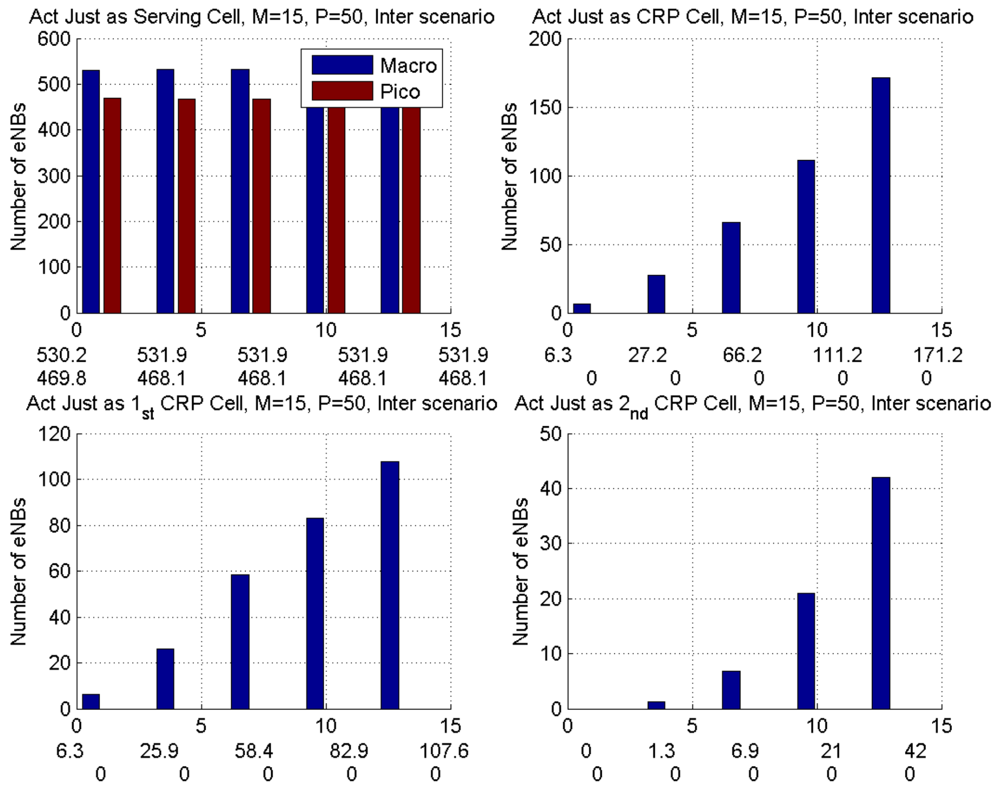




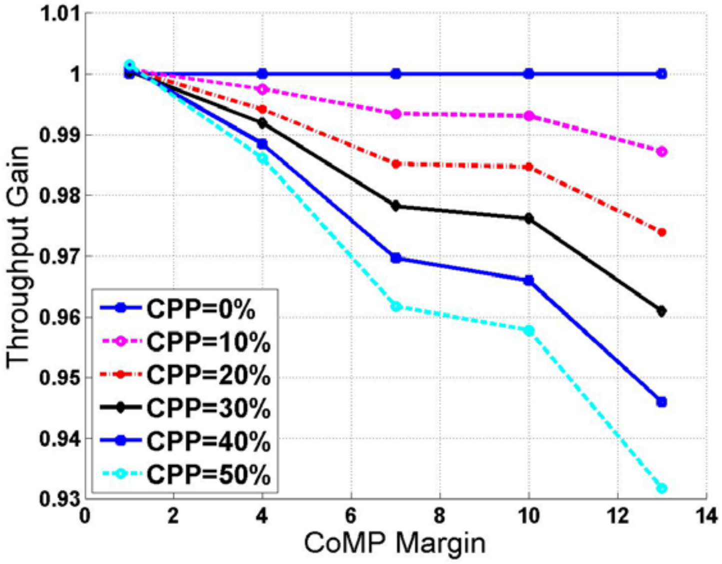
Inter Scenario

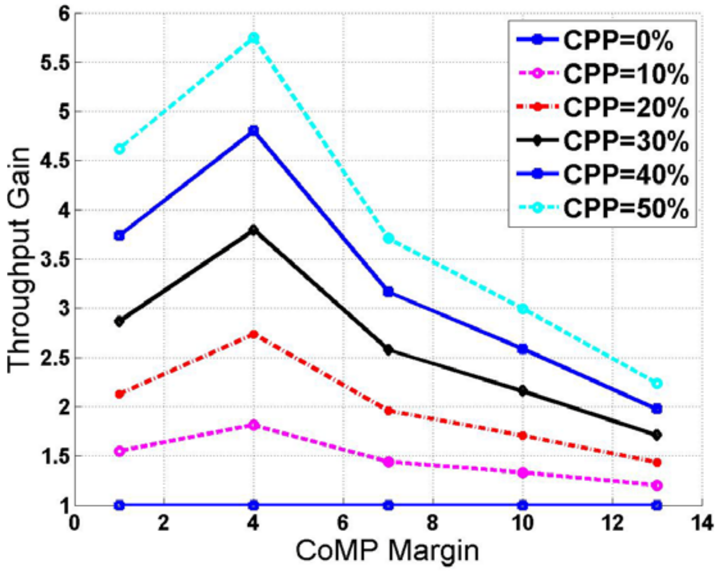


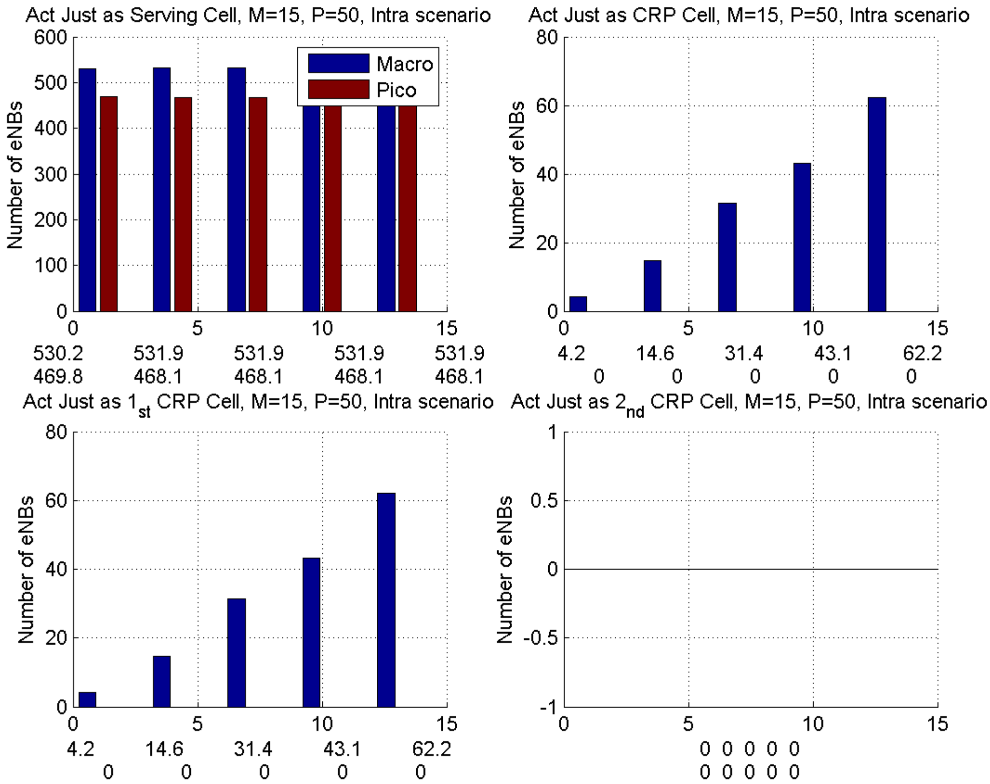




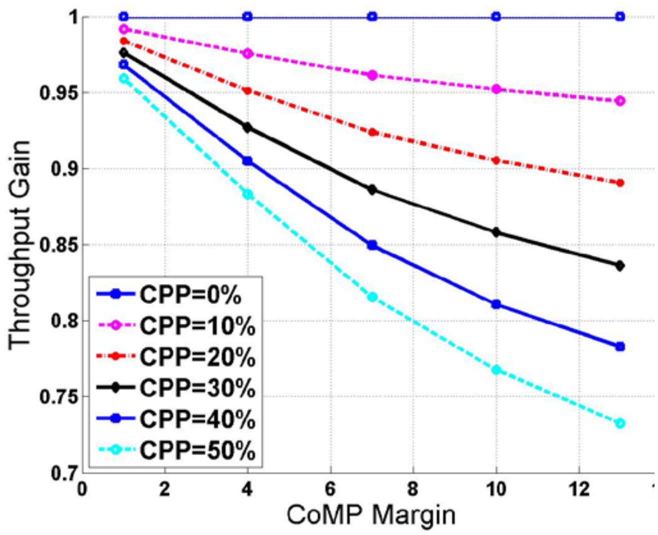
Intra Scenario

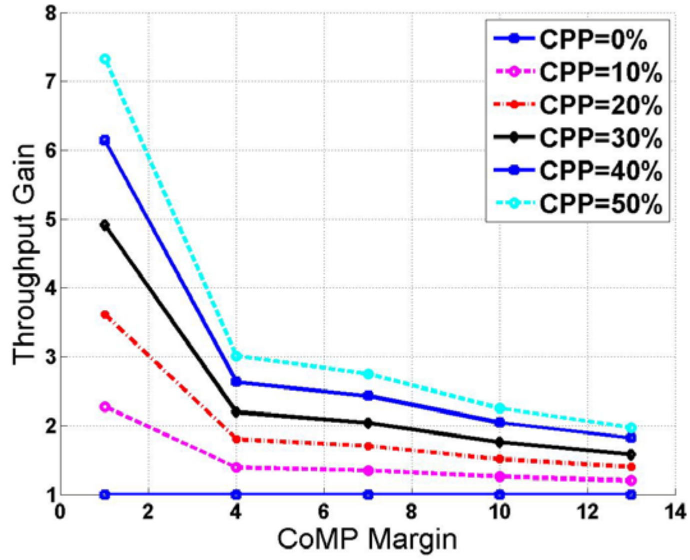


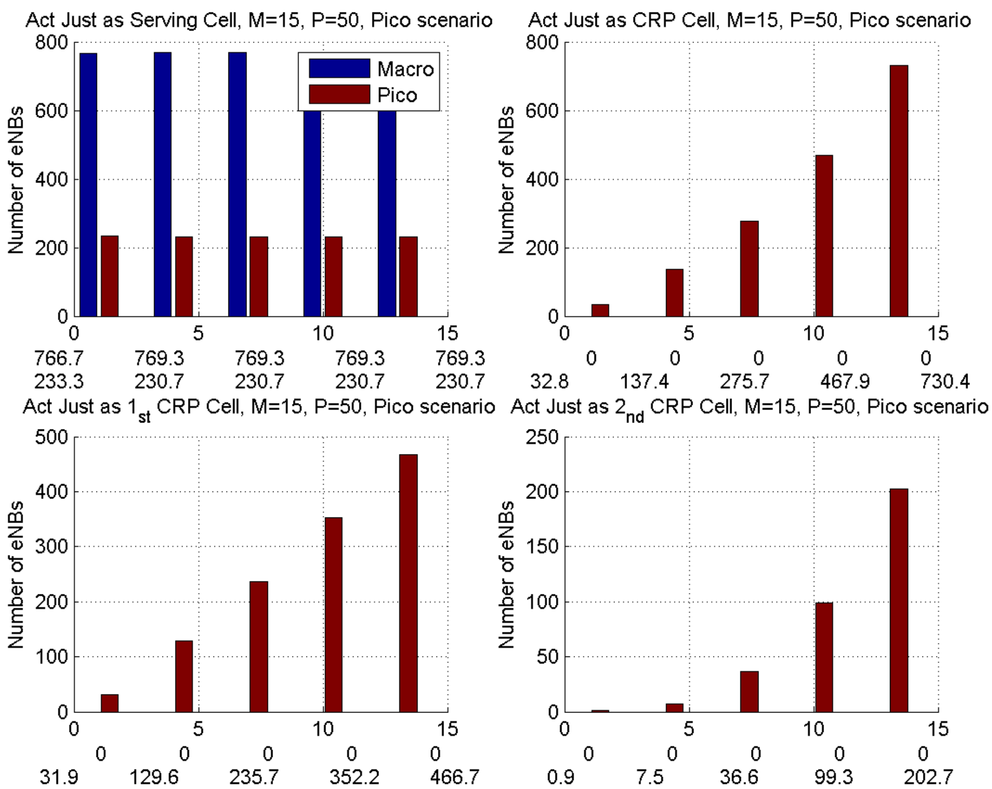




Small (Pico) Scenario



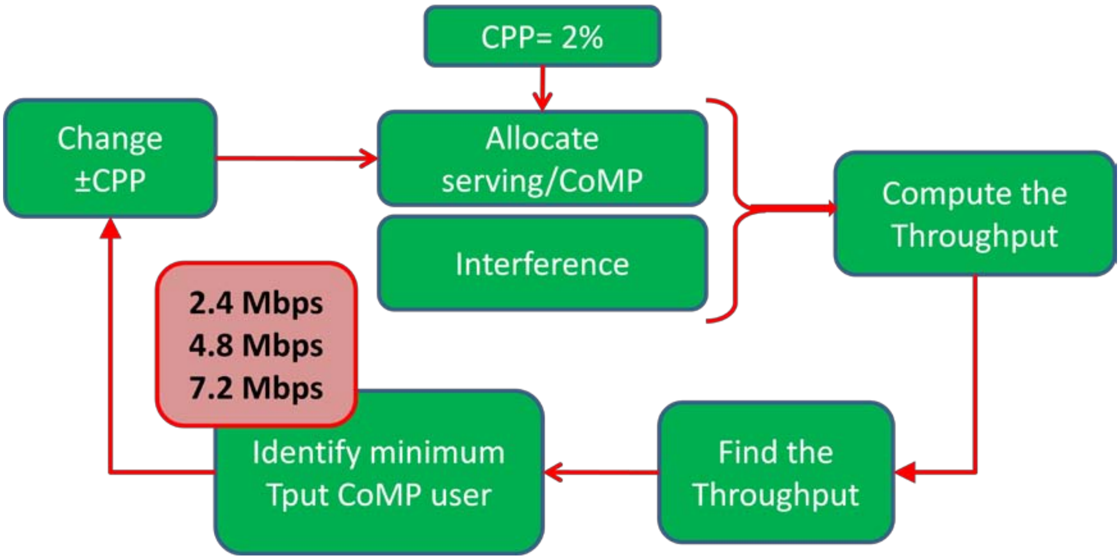




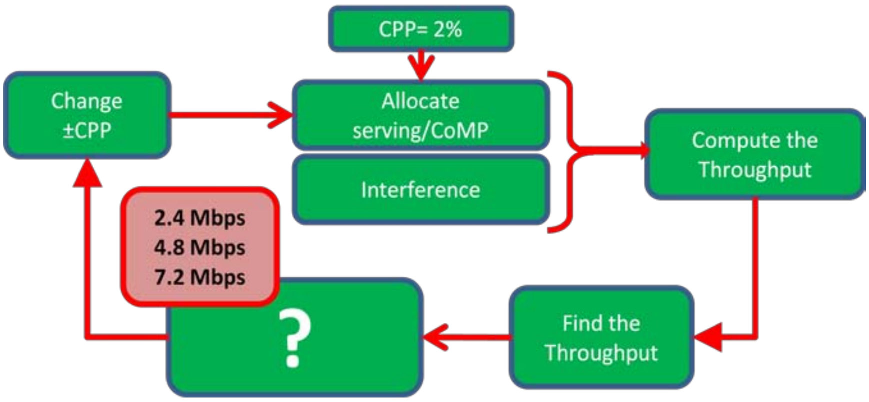
Chapter 4

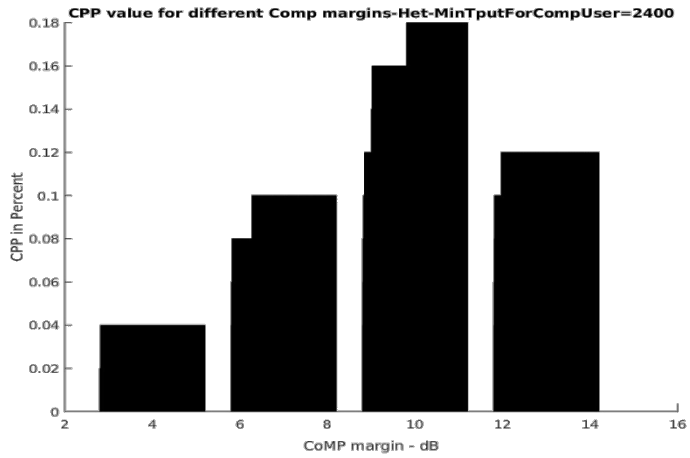
Minimum Guaranteed Throughput Algorithm

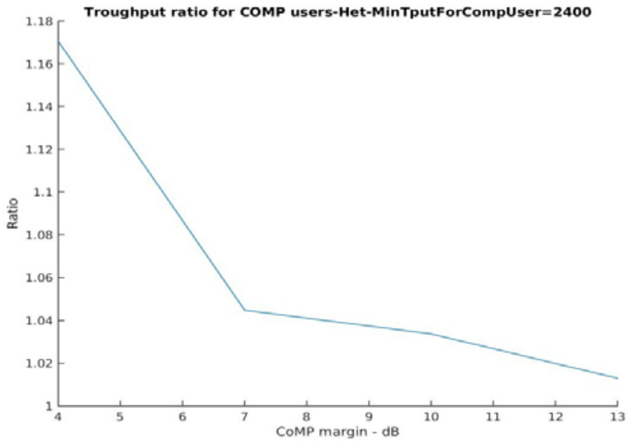
We define 3 different values for minimum Throughput for CoMP users and based on that value in a close loop process the CPP is changed.

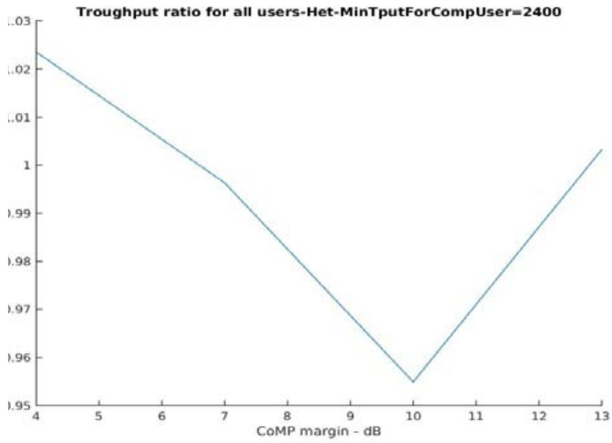


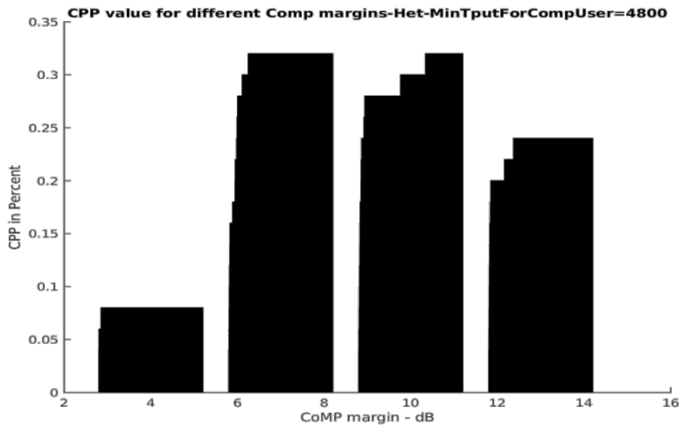
- The minimum throughput value for CoMP user (Mbps) is a function of so many parameters in the network layer.
- The results obtained according to this parameter could be different in other scenarios
- Let apply a comparative strategy in term of throughput of CoMP and normal users.
- The minimum throughput of CoMP user could not be more than an average on certain percent of normal users with least throughput.(5% or 10%)

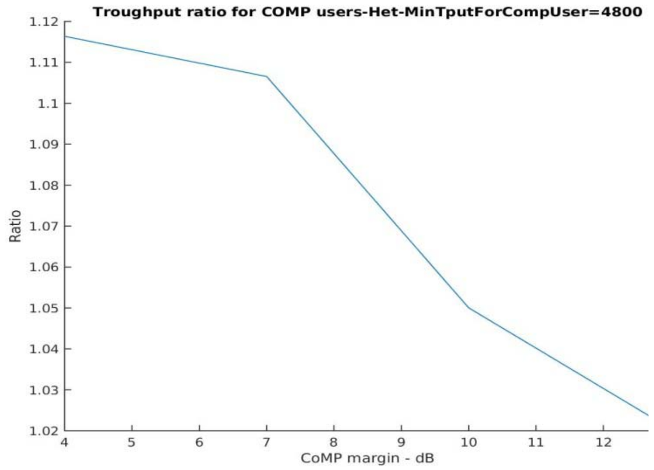


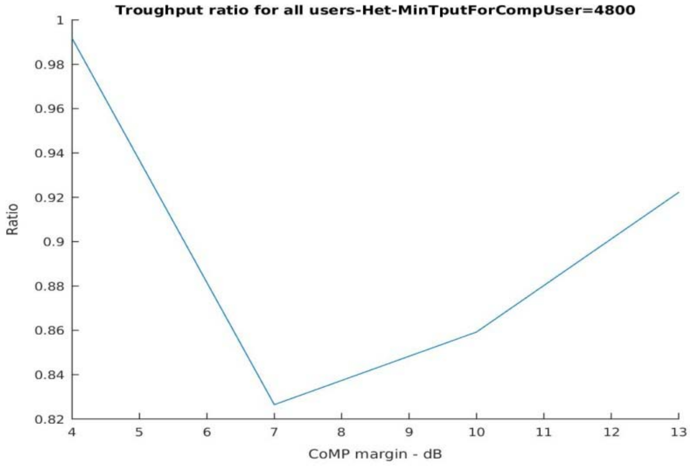

CPP value for different Comp margins-Het-MinTputForCompUser=2400
CPP in Percent
CoMP margin - dB

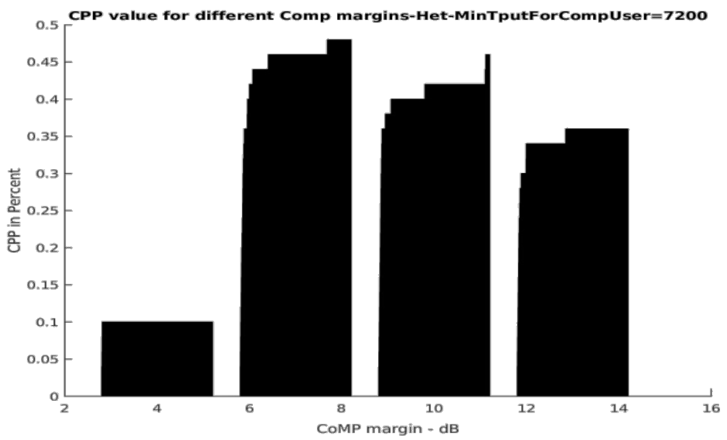

Troughput ratio for COMP users-Het-MinTputForCompUser=2400
Ratio
CoMP margin - dB

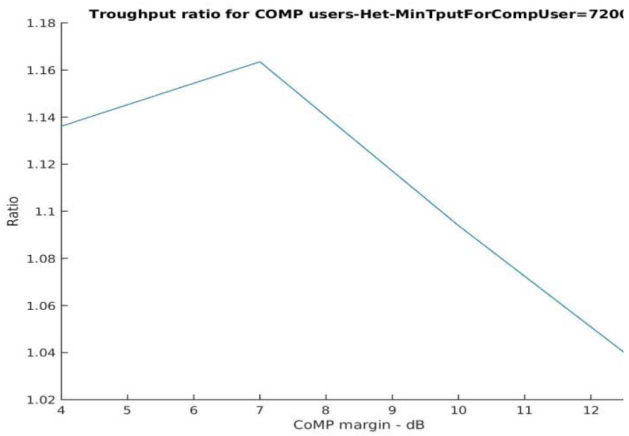

Troughput ratio for all users-Het-MinTputForCompUser=2400
CoMP margin - dB

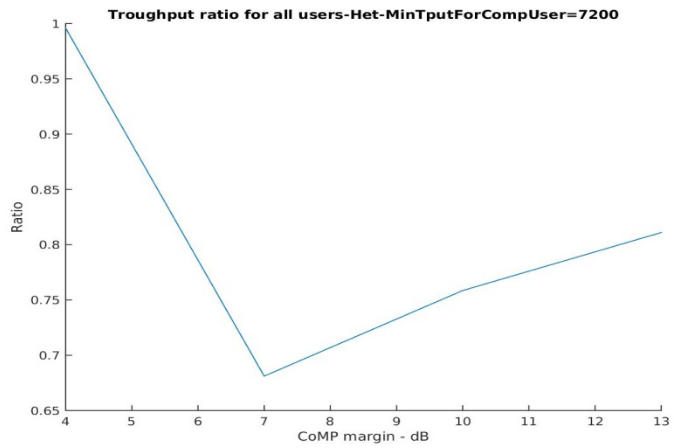

CPP value for different Comp margins-Het-MinTputForCompUser=4800
CPP in Percent
CoMP margin - dB


Troughput ratio for COMP users-Het-MinTputForCompUser=4800
Ratio
CoMP margin - dB


Troughput ratio for all users-Het-MinTputForCompUser=4800
Ratio
CoMP margin - dB

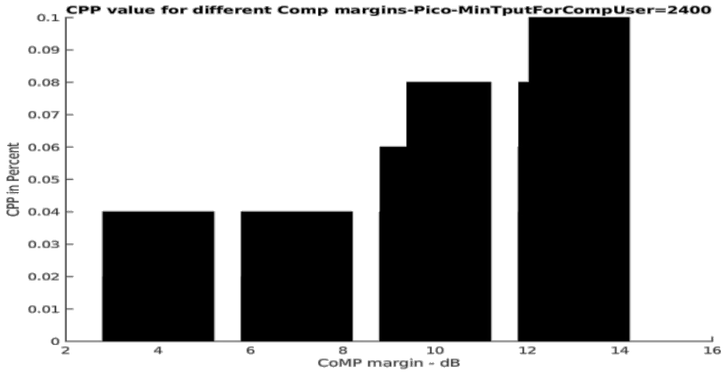


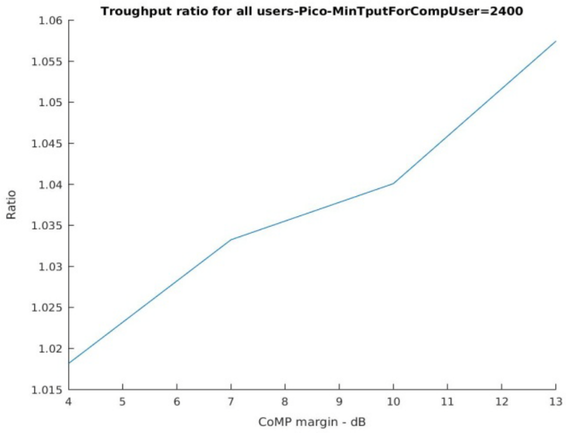


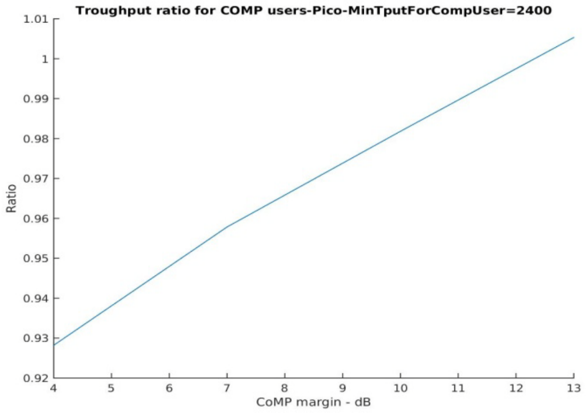


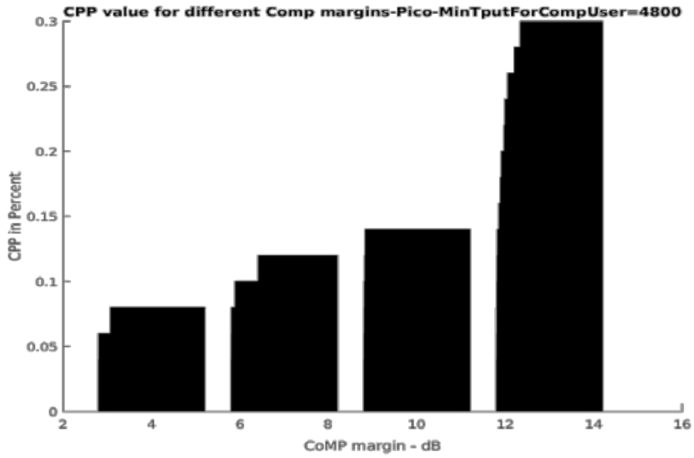
We set the minimum Throughput for Heterogeneous scenario in 3 different set of simulation 2.4, 4.8, 7,2 Mbps respectively.

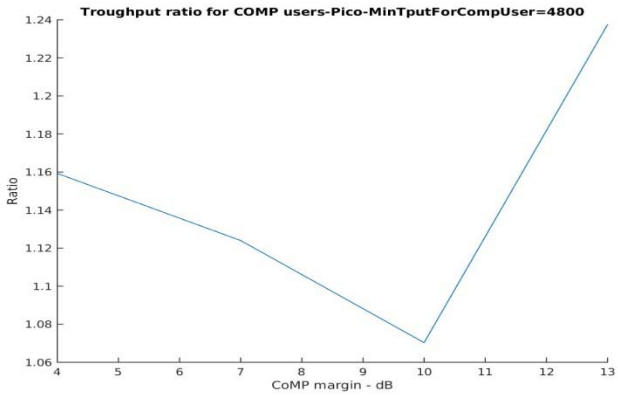
- In 2.4 Mbps case, both with CoMP over without CoMP for all users (upper left) and for just CoMP users (upper right) tend to decrease with increment of CoMP margin, but the ratio is still around one.
- There is a profundity in CoMP margin = 10 for CoMP users which is exactly happened when the CPP is increasing.
- An opposite manner for CPP and CoMP users throughput ratio can be seen in the graphs.
- Because of the minimum guarantee for CoMP users, in CoMP margin= 10, seems to occur an imbalance for number of CoMP users and portion of dedicated resources ,which turns out to be a loss
- Increasing the CoMP margin, more users can contribute in CoMP process.
- Depends to the network layer properties, a bizarre behavior can be seen in the graphs , where minimum guaranteed throughput is achieved with less CPP.
- Having more and farther users contributing in CoMP in some point means that they are already enough close to their associated serving eNB and the notable portion of minimum throughput was already provided by the serving cell.
- In 7.2 Mbps case, the loss for all users gain is up to 30%.

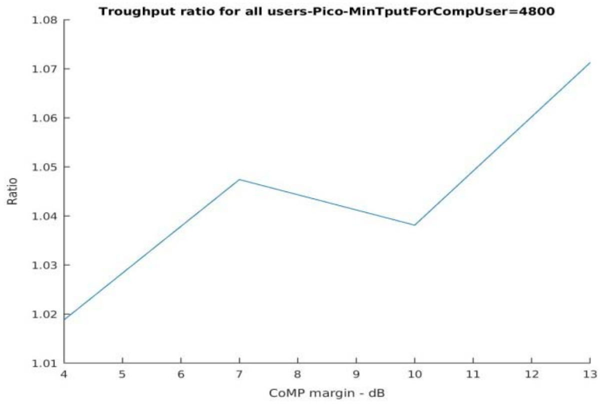

CPP value for different Comp margins-Pico-MinTputForCompUser=2400
CPP in Percent
CoMP margin - dB

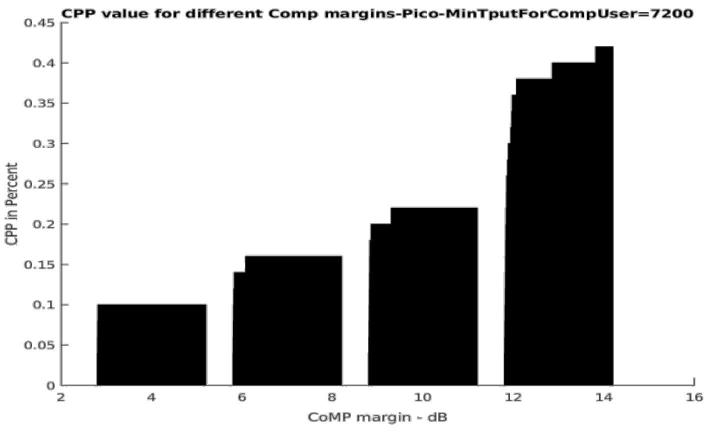

Troughput ratio for all users-Pico-MinTputForCompUser=2400
Ratio
CoMP margin - dB

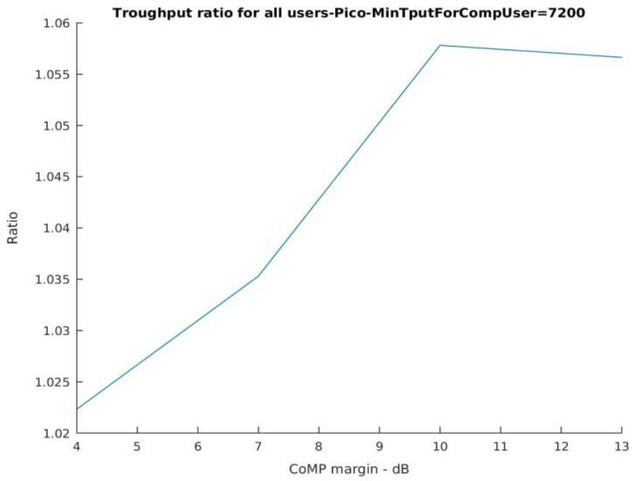

Troughput ratio for COMP users-Pico-MinTputForCompUser=2400
Ratio
CoMP margin - dB

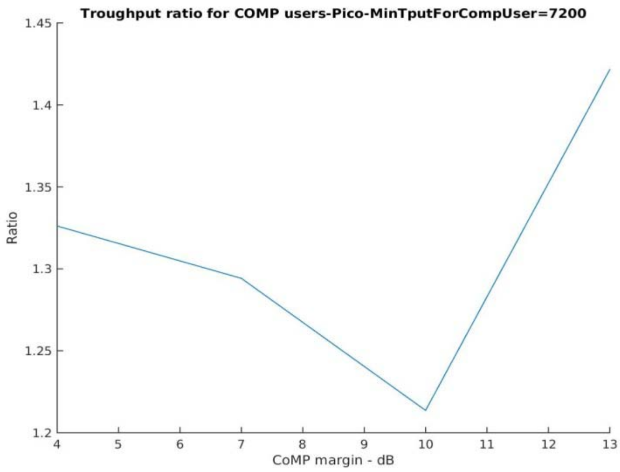

CPP value for different Comp margins-Pico-MinTputForCompUser=4800
CPP in Percent
CoMP margin - dB


Troughput ratio for COMP users-Pico-MinTputForCompUser=4800
Ratio
CoMP margin - dB


Troughput ratio for all users-Pico-MinTputForCompUser=4800
Ratio
CoMP margin - dB







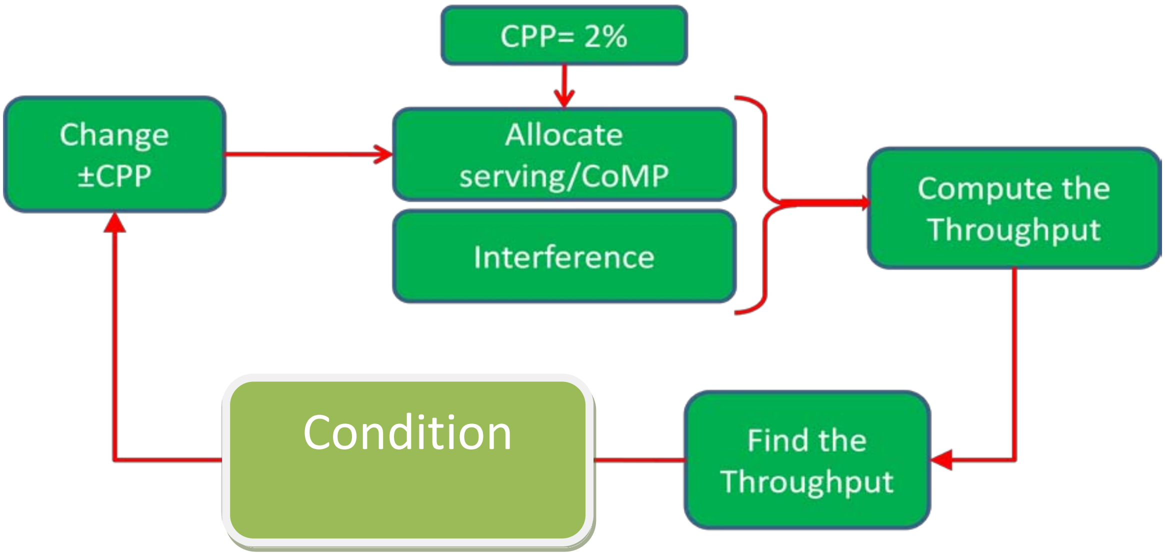
- In small scenario just small cell can perform CoMP functionality.
- In 2.4 Mbps setting there is a constant increment in throughput gain with respect to CoMP margin.
- According to the nature of the small cell and scenario and coverage and the constraint of having more users around small cells, CPP portion can be more dedicated to CoMP users (up to 10%) without losing the gain for even the whole network. This means that regular users are well supported and being serviced by their associated serving, most of the time Macro cell, eNB.
- In small Scenario, 4,8 and 7.2 Mbps simulations the CPP value increased up to 30% and 44% respectively.
- It is Very interesting that both gains for all users and CoMP users are more than 1.
- The small scenario could be a good and efficient sample of CoMP deployment according to this set if simulation

Adaptive CPP - General specification

As we discussed last time, we desired to observe the response of the system, variation of CoMP pool percentage value, in terms of number of users. The current simulation has been done by the following specifications:

Number of Macro-cells	8 or 24 cell
Number of Micro-cells	12
Number of clusters	2
Number of users	500-166-333
Scenario	Heterogeneous
Pathloss	Pathloss model for Macro and Micro
Fast fading - Simulated	Random Trace selection
Scheduler Refreshment time	1 TTI = 1ms
Decision time to refresh CPP	100 TTI = 100 ms
Total simulation time	8 second
CoMP margin	4 dB-7dB-10dB-14dB

According to the current simulation, the results are gathered in four periods of two seconds. In the first 2 seconds we run the simulation initiating with CPP= 2% and let the system to adopt the best value of CPP according to the defined condition.



Condition

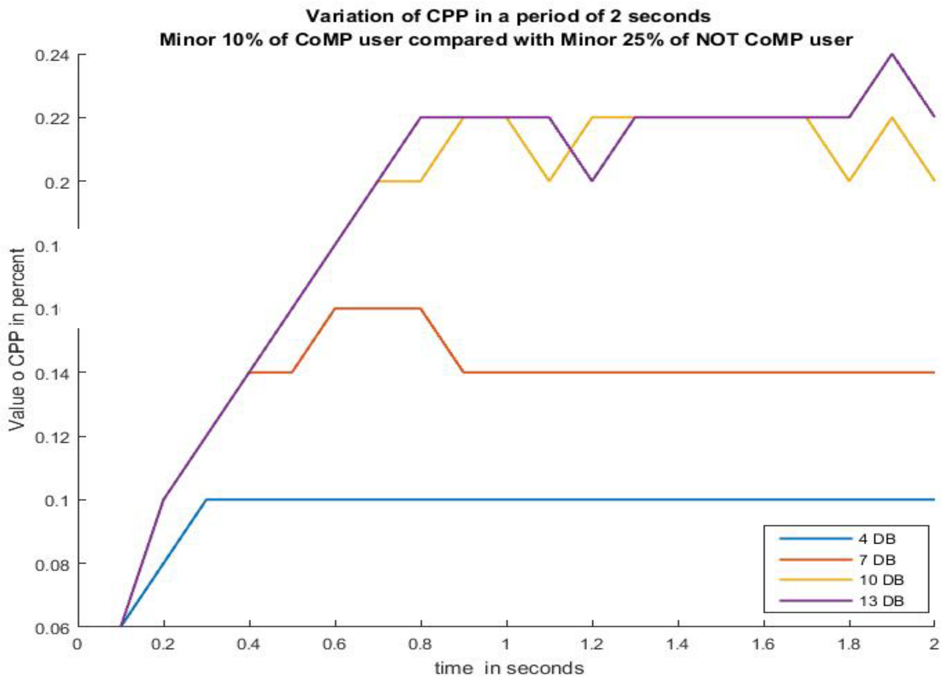
In last set of simulation the condition is set to be a guarantee in terms of throughput for the CoMP user with the minimum throughput or worst condition. The guaranteed value for the minimum throughput for the CoMP users were set to be 2400, 4800, 7200 kbps. However mentioned value had a nonlinear impact and singularity on the behavior of the network.

We decide to set a relative condition to change the CPP value in the network. The first idea was to compare the CoMP user has the minimum throughput with a user which does not use CoMP functionality with the least throughput in the network. The drawback of this method is the singularity which can be seen in the feedback loop of the system. The users (using CoMP or not using CoMP) may change in every TTI and its throughput according to the fast fading effect and other users interference is subject to change for every time snapshot.

In order to have a relative condition and remove the singularity in our scenario, we decide to set an average of throughput of a certain percentage of users with minimum throughput as a reference to compare between users using CoMP and without the CoMP functionality.

The first set of simulation is done with the heterogeneous scenario and we decide to adjust above percentages to 10% for the CoMP users and 25% percent for the regular (not CoMP) users. In another word, the average throughput of the 10% of the users who are using CoMP with least Throughput is compared to the average throughput of the 25% of the users who are not using CoMP functionality with least Throughput.

In the following plot the Variation of the CPP for different value of CoMP margin, in first 2 seconds can be seen (500 user):



- o Accelerated increment when the difference between average of throughput is notable
- o Regular increment of 2% when the difference in not so much

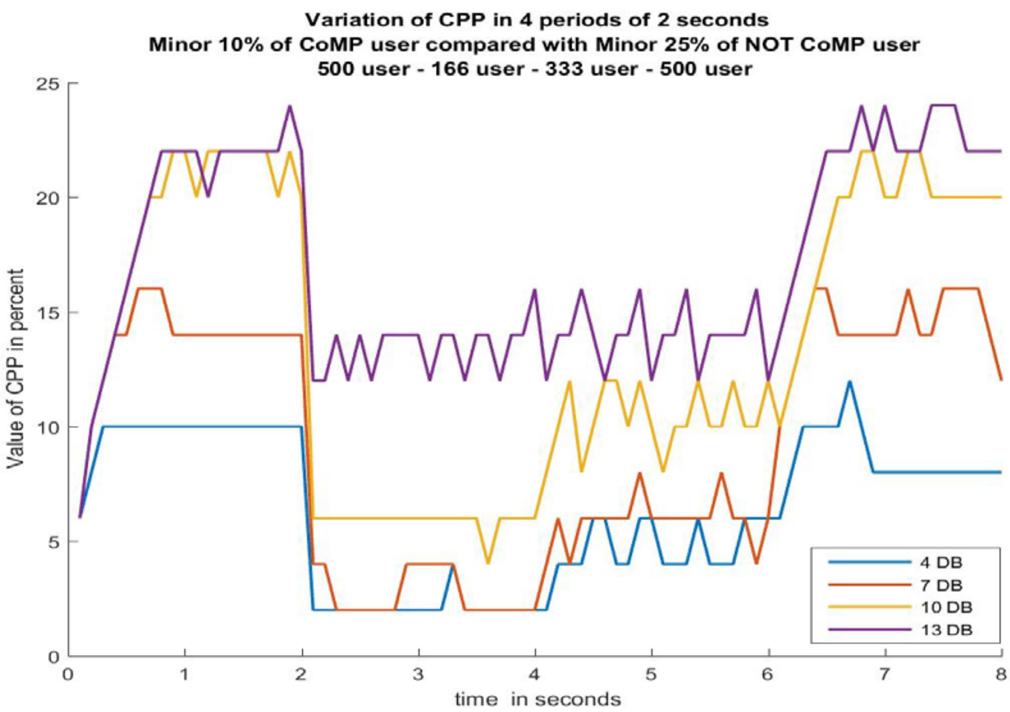
- Decrements

$$CPP_{Next} = 0.02 * \left\lfloor (CPP_{current} * 50 * \frac{Throughput_{NoCoMP}}{Throughput_{CoMP}}) + 1 \right\rfloor$$

Idea development

We peruse my simulation with 2 second of time window for different number of the users (500 , 160, 330, 500-1). So we can see the variation of the CPP in sequential time periods with different number of users. It is needed to mention that whenever the number of users is changed, initial value of the CPP for each CoMP margin simulation for the new set of the simulation with new number of users is the same as the last value of CPP in the most recent one. In this form we also maintain the continuity of the CPP function and the observation of the variations are meaningful.

Following graph shows the variation of the CPP in 8 second of simulation with different number of users.



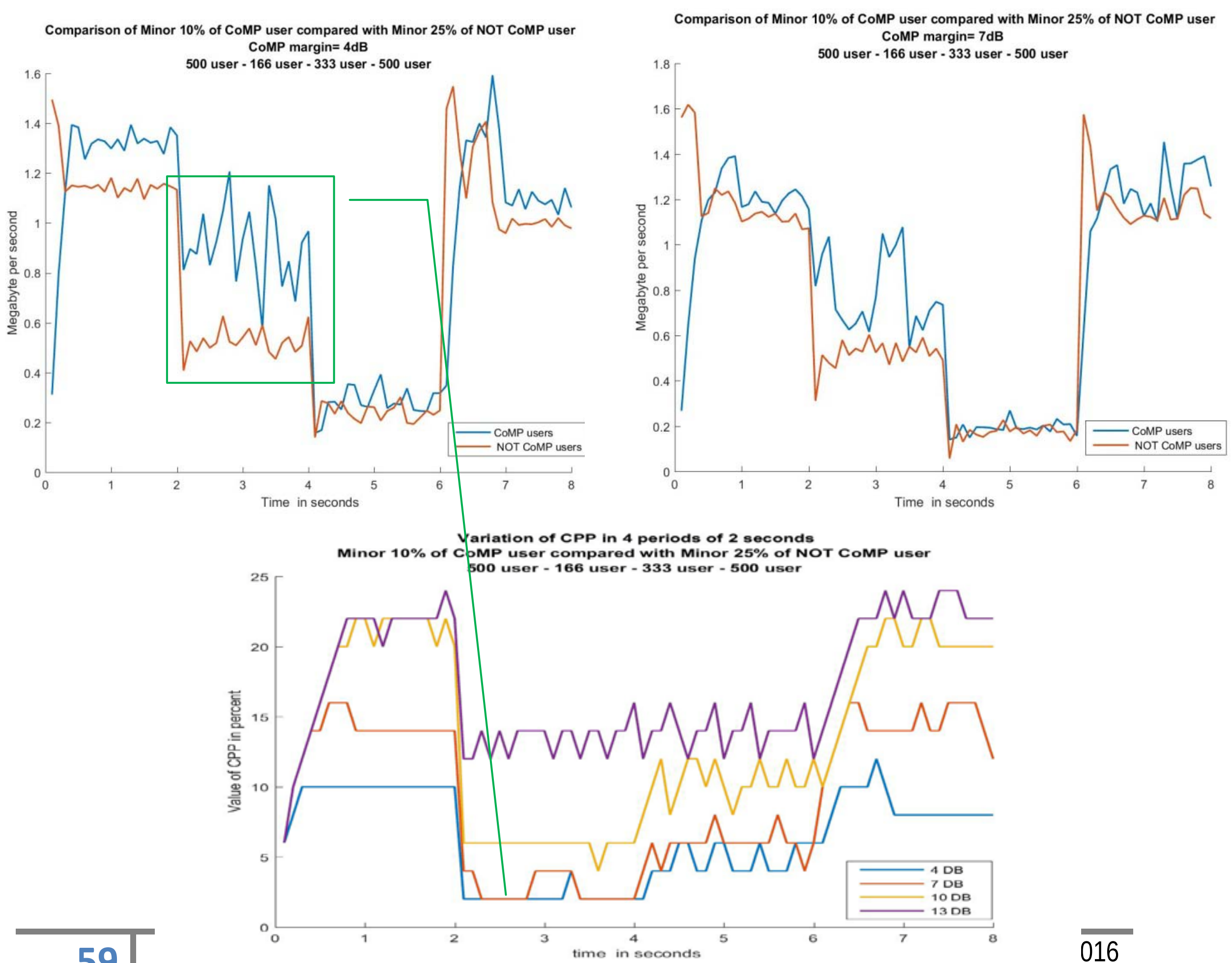
Graph description

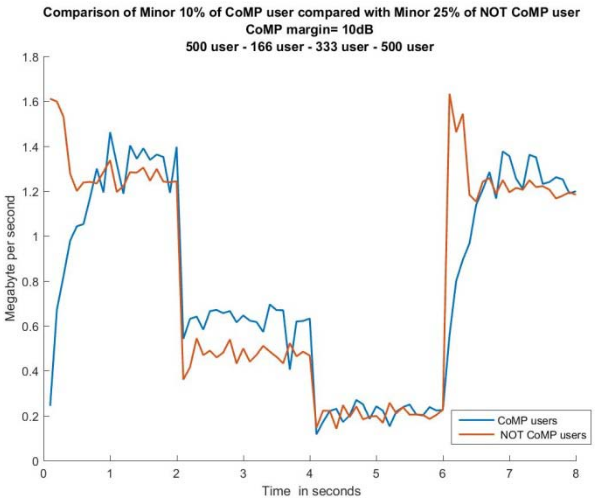
The graph shows the CPP behavior in 4 set of continues simulation with different number of users (500,166,333,500-1) for 4 different values of CoMP margin. As it is shown the in first 2 seconds CPP value always converges to a certain percentage according to the condition set. In second time window which the number of users are decreased to 166 the CPP value also follow the degradation manner. By increasing the number of users to 333 in 3rd time window CPP values are also rise for all CoMP margins. And finally for the last time window which all the users are in the network again, CoMP pool percentage regain the stabilized values which reached in end of first time window (1.5 to 2 sec).

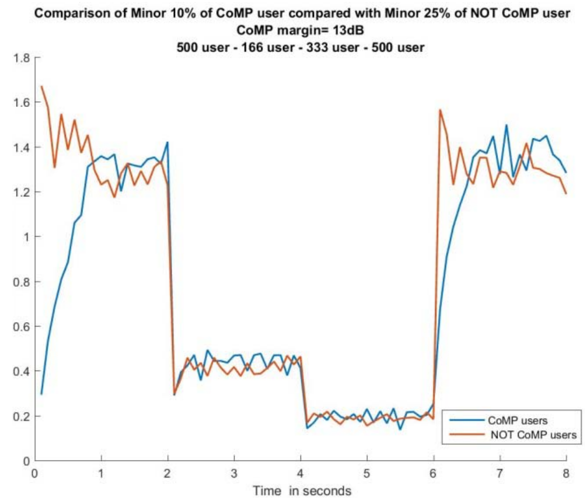
What is challenging?

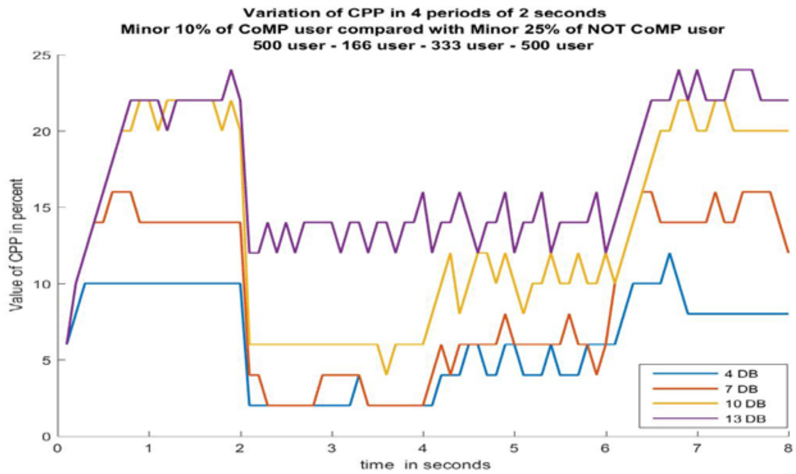
During the simulation I check out the throughput averages which set by condition, and I figured out that these averages are getting much lower compared to the simulation with higher number of users. So we decide to analyze the numbers obtaining during the simulation in order to find a better and more efficient condition.

In the following graphs we can see physically the condition which changing the CPP value:



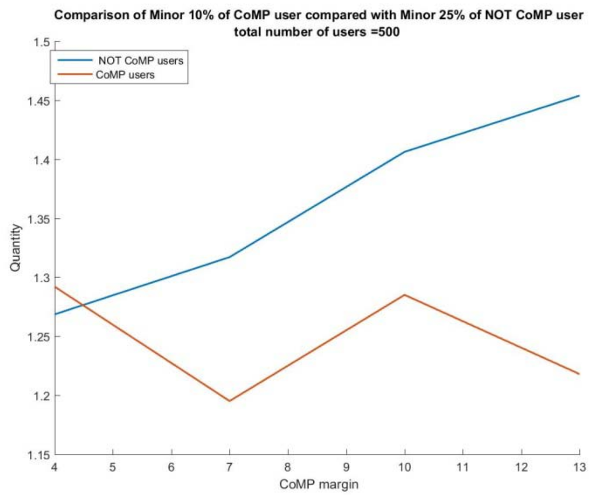


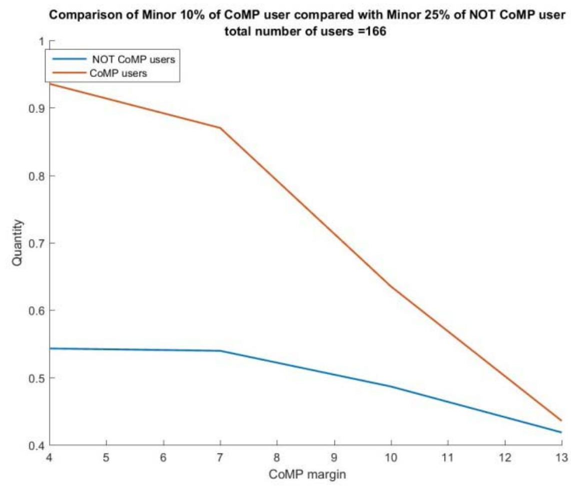


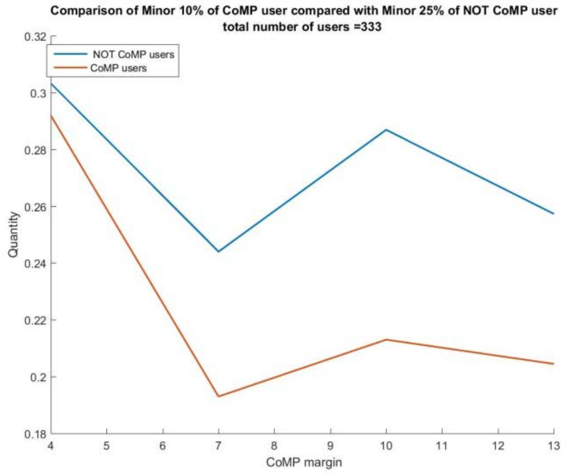


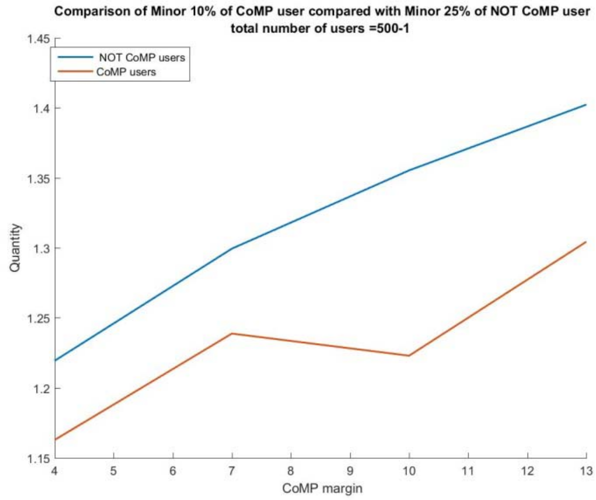
In all graphs a twisted behavior is seen, this is a consequence of the feedback loop which set the CPP somehow that two values of averages are usually compared. In lower CoMP margin values especially when the CPP value is lover than 6%, the twisted shape is rarely seen. When the difference is not so much and CPP ratio is inappropriate that the feedback loop can modify the CPP value.

In other graphs we show the comparison according to CoMP margin:



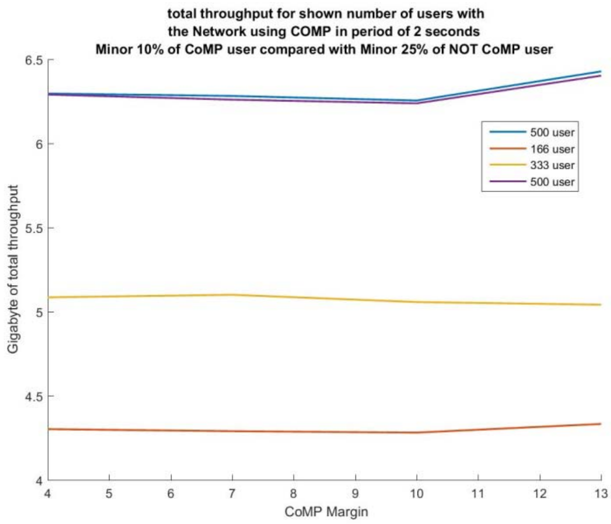


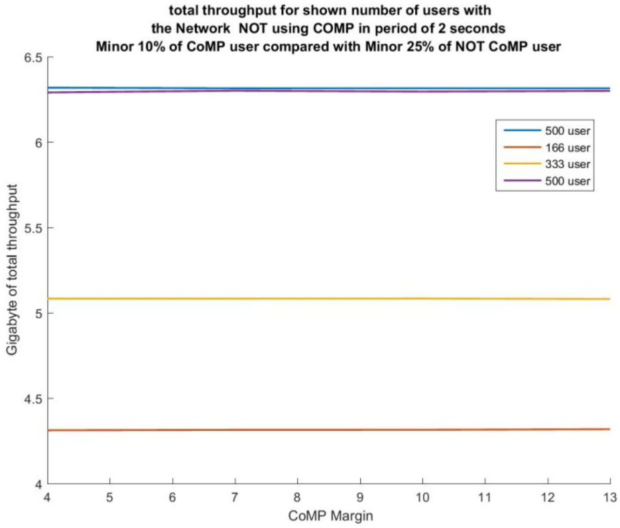


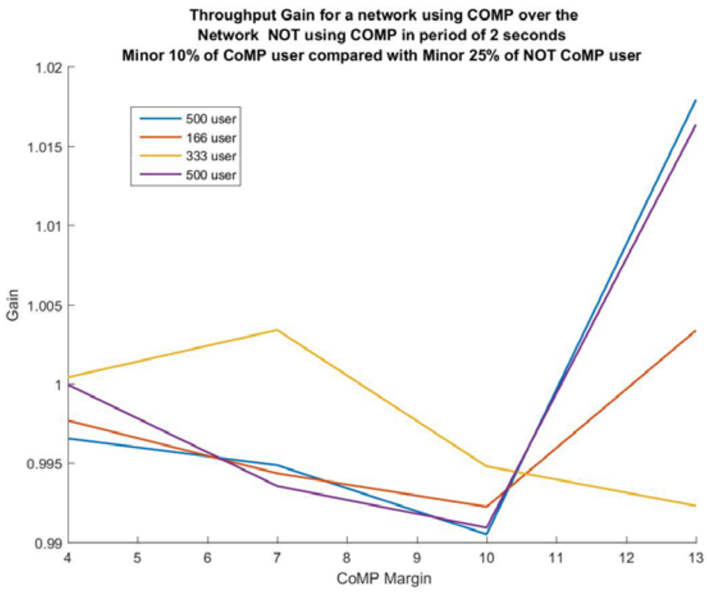


Total Throughput check and gain

Experiencing the decrement in average throughput by decreasing the number of the users made us supervise the behavior of the network in terms of total provided traffic and CoMP functionality gain.

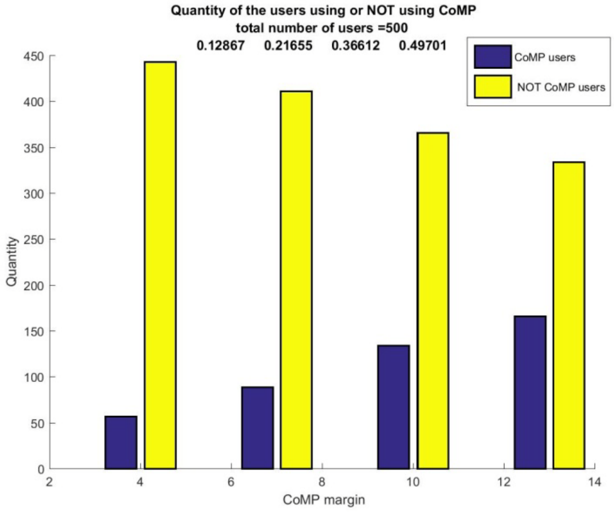


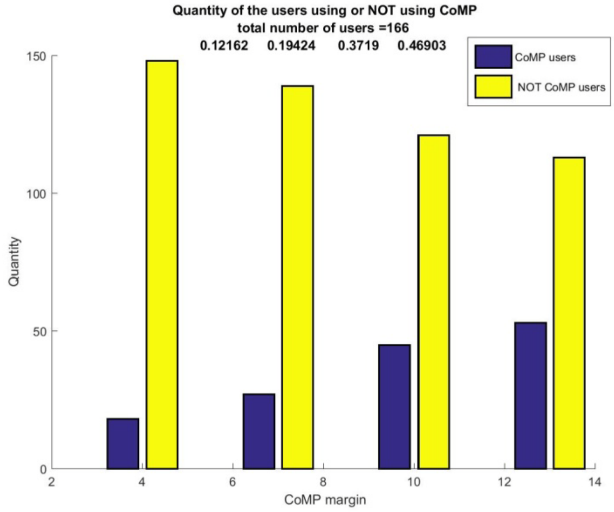


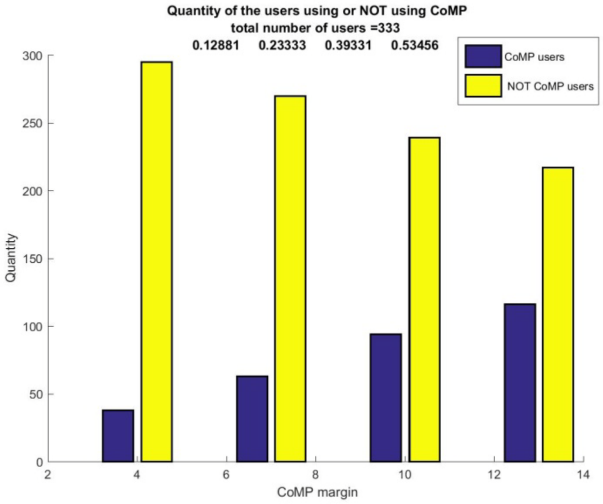


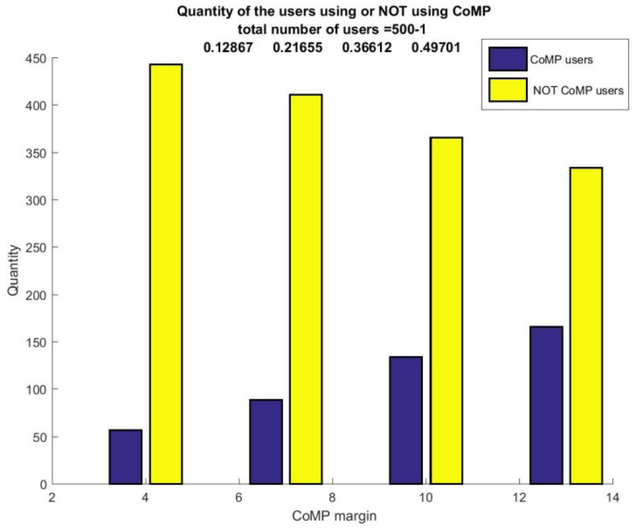
Users Number and Ratio of users using CoMP in each scenario

Each of the following bar charts is belong to a consecutive time window of 2 seconds with dedicated number of users. The lower right graph belongs to the time which the number of users regain the initial value of 500.





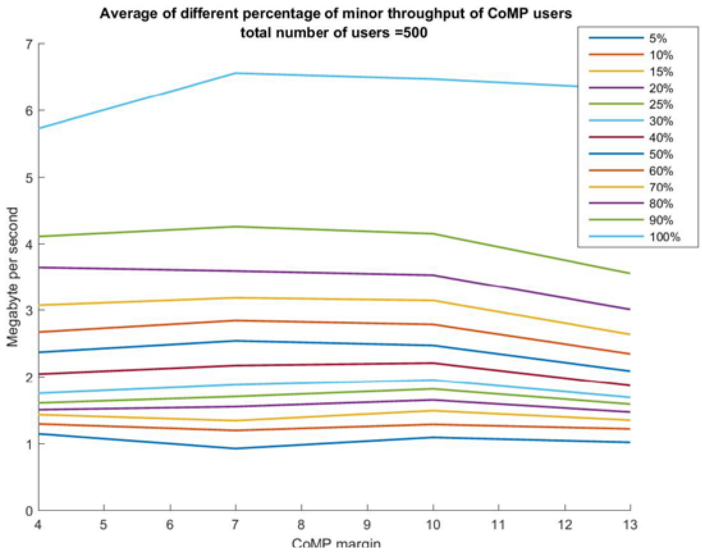


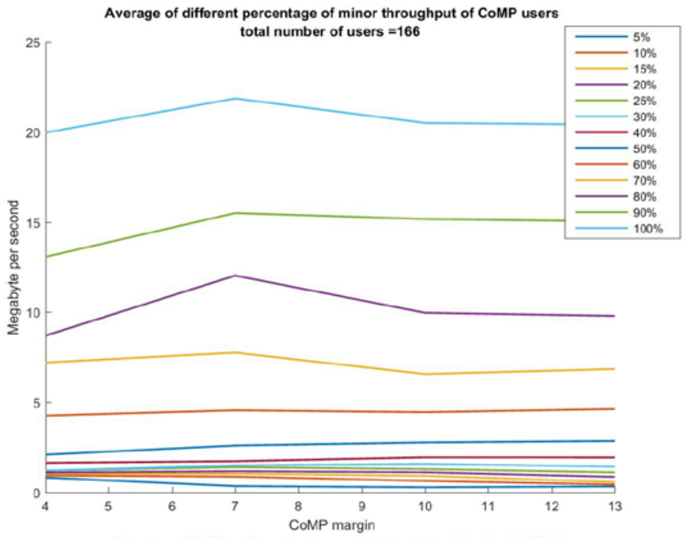


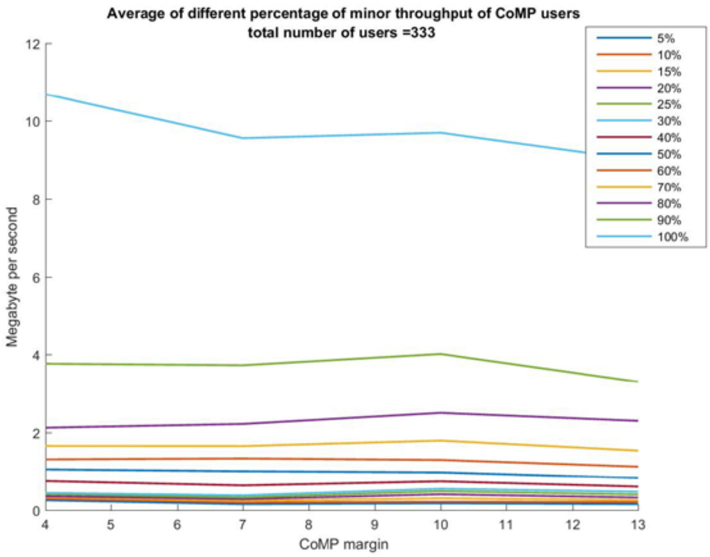
Using Different percentage of minor users in terms of throughput

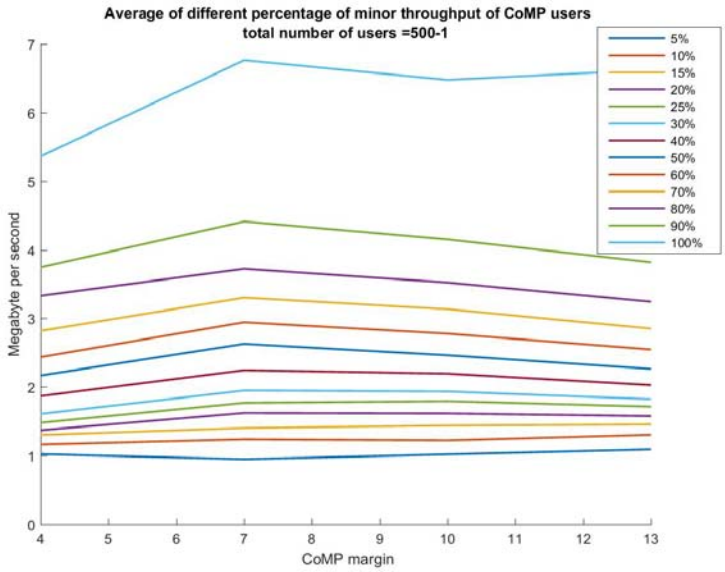
An idea of using 10% of minor CoMP users and 25% of minor non CoMP users can be changed into other percentages. The optimized value, or in general condition, can be better extracted by microscopic view of the throughput in time and CoMP margin domain.

Following graphs show the average over the different percentage of minor CoMP users in terms of throughput base on CoMP margin.

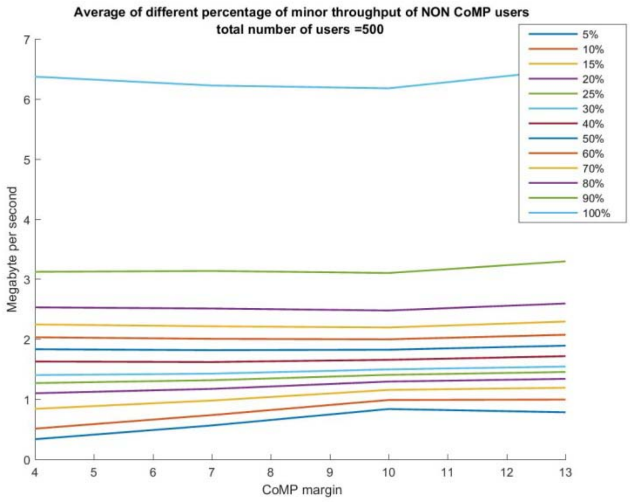


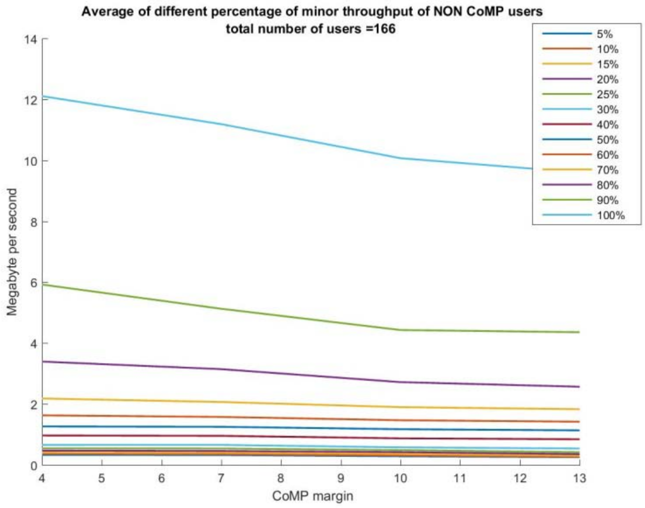


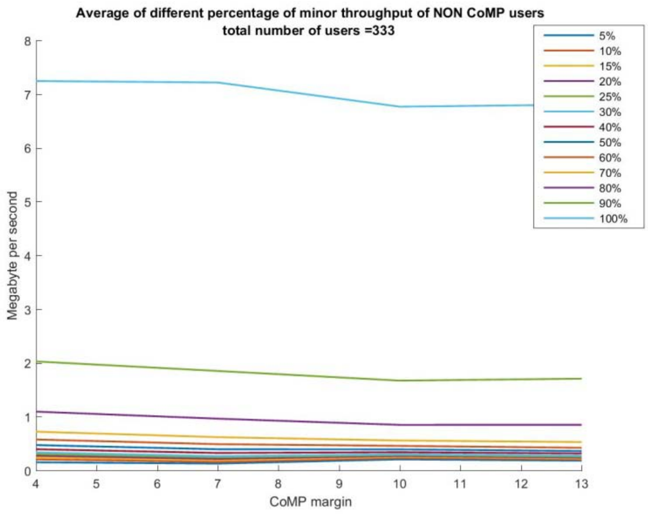


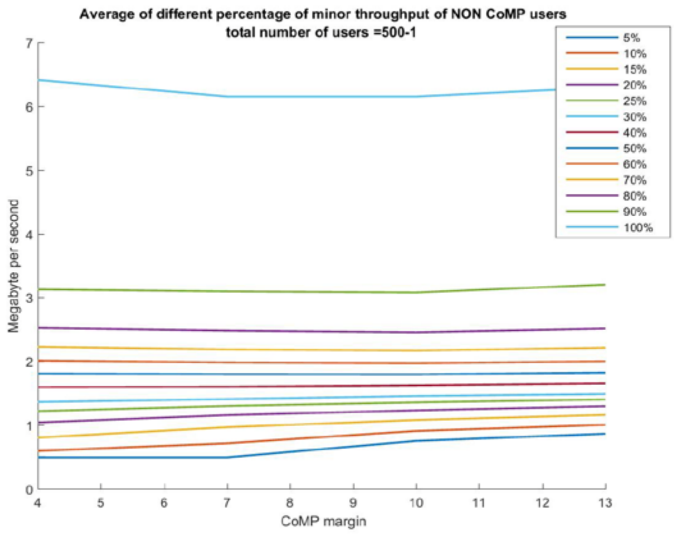


Following graphs show the average over the different percentage of minor NON CoMP users in terms of throughput base on CoMP margin.

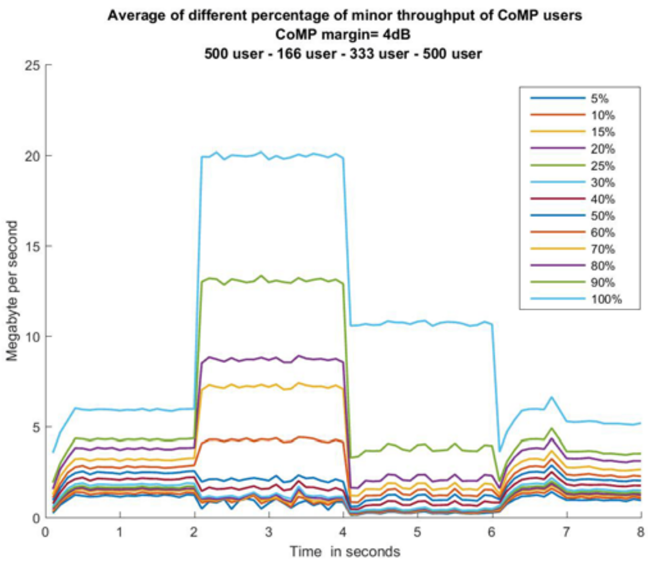


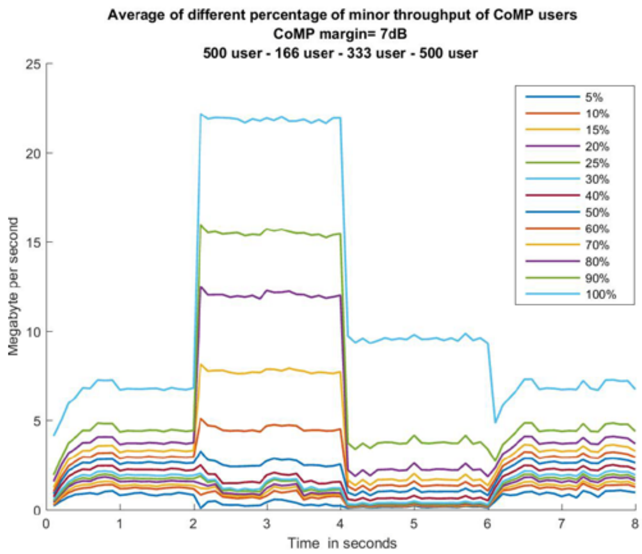


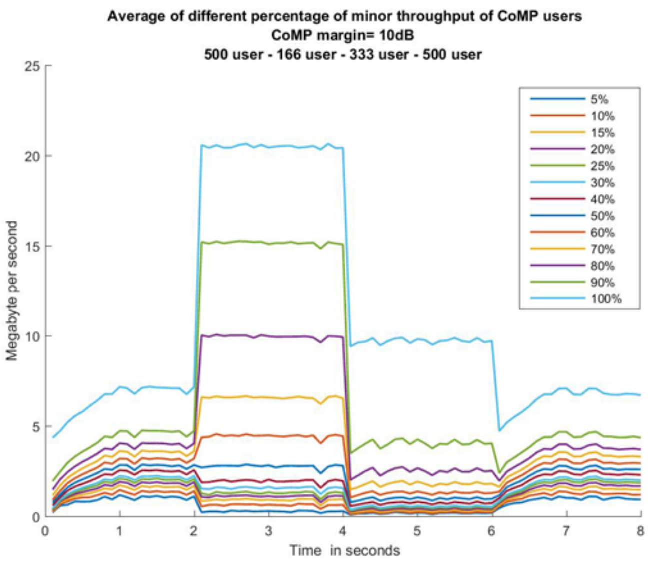


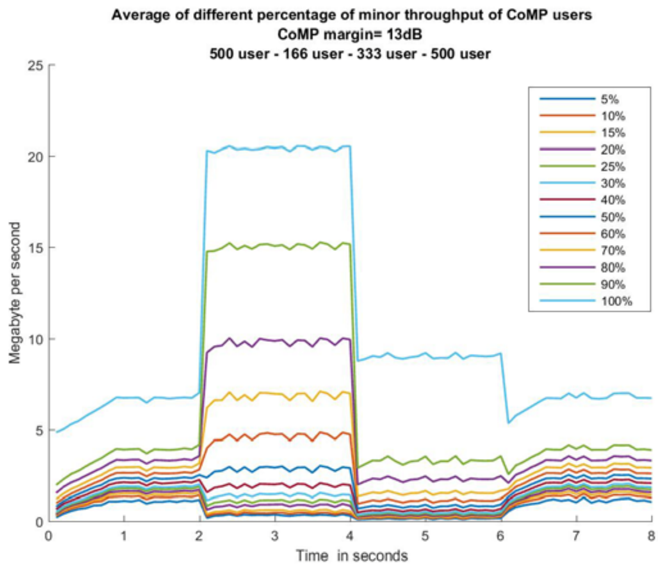


Following graphs show the average over the different percentage of minor CoMP users in terms of throughput base on total simulation time for each CoMP margin.

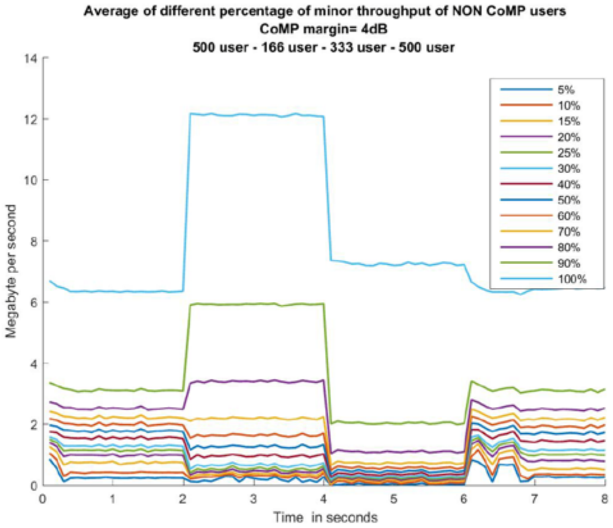


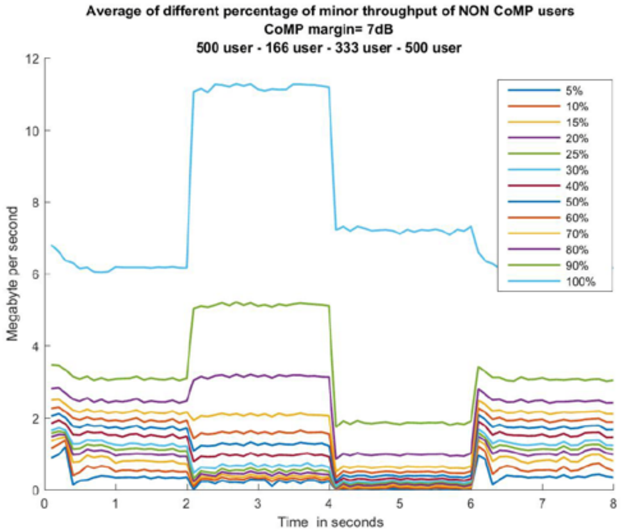


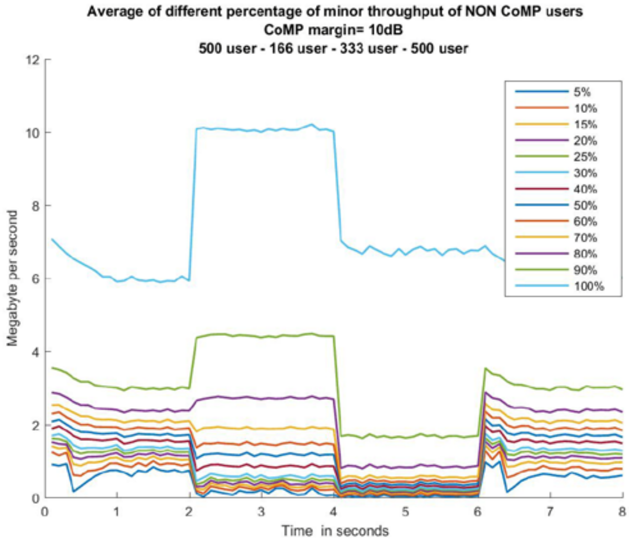


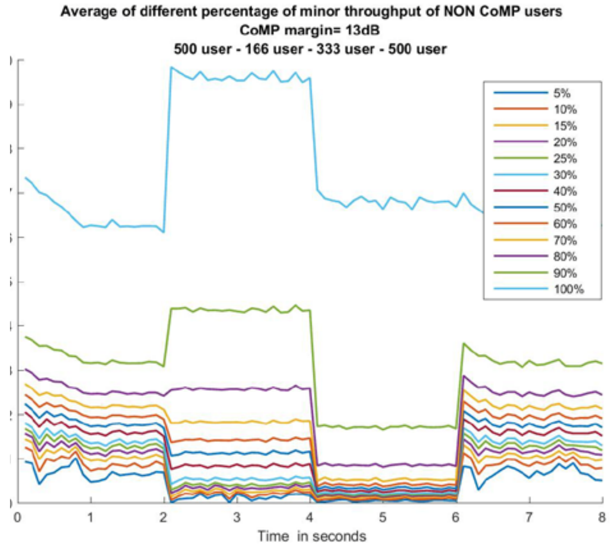


Following graphs show the average over the different percentage of minor NOT CoMP users in terms of throughput base on total simulation time for each CoMP margin.

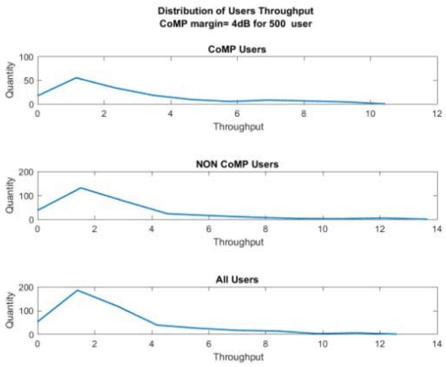


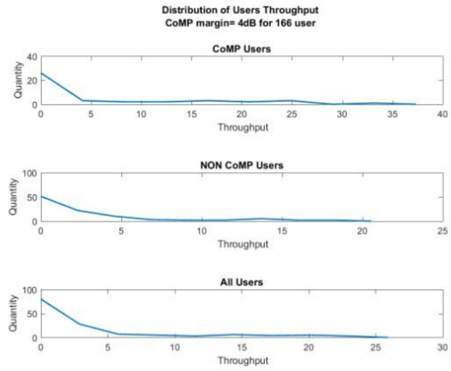


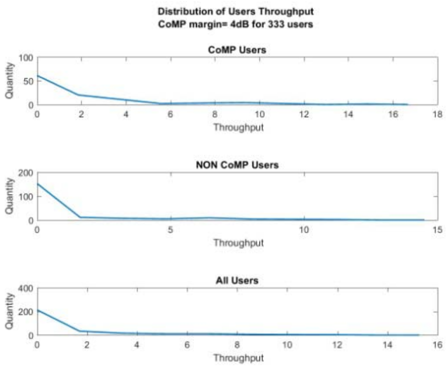


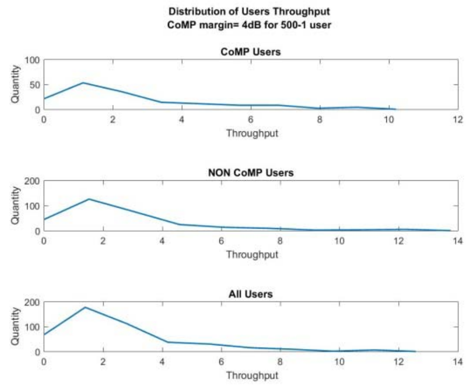


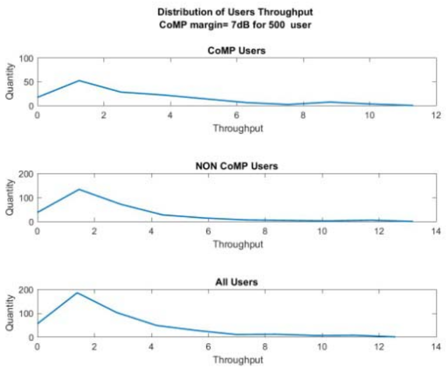
User throughput Distribution

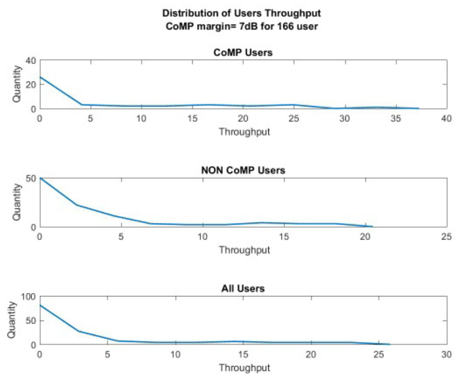


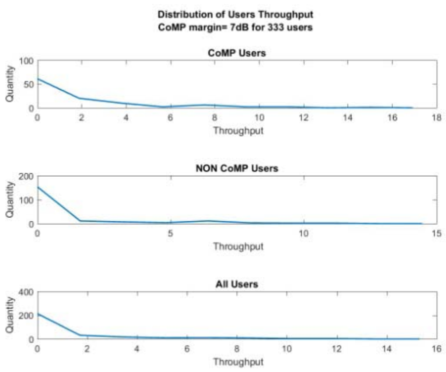


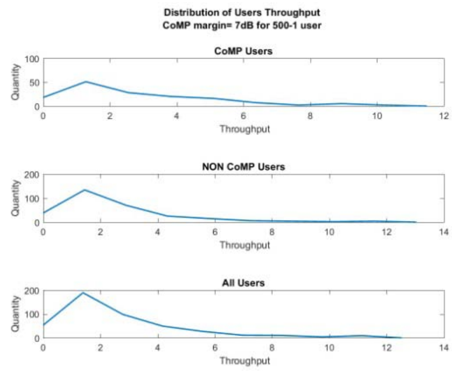


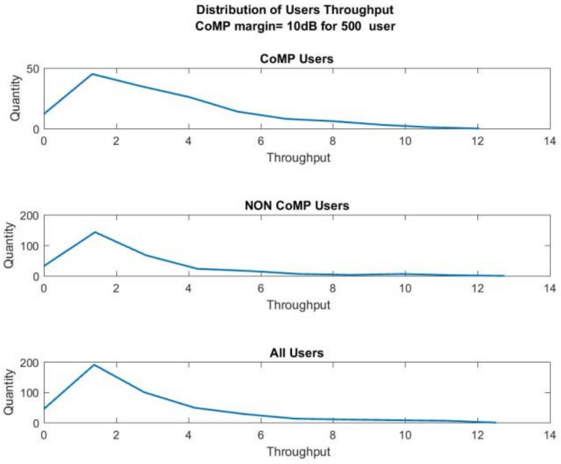


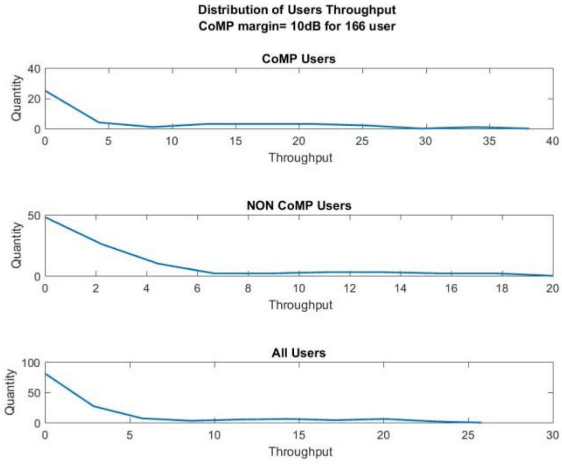


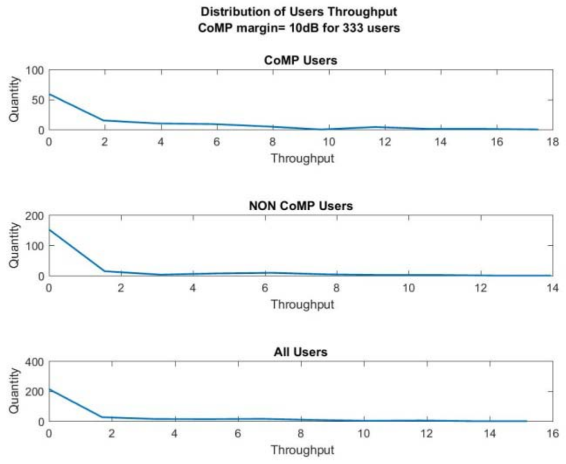


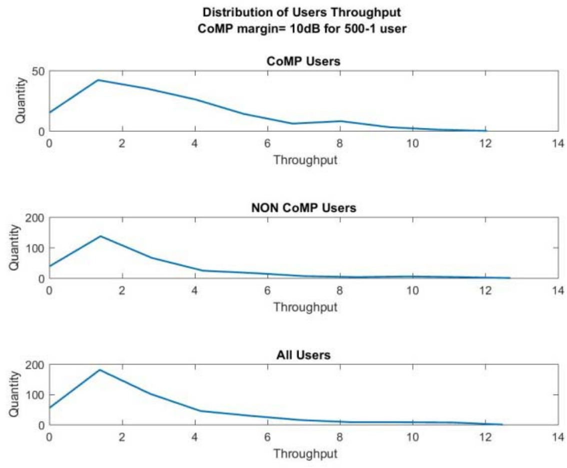


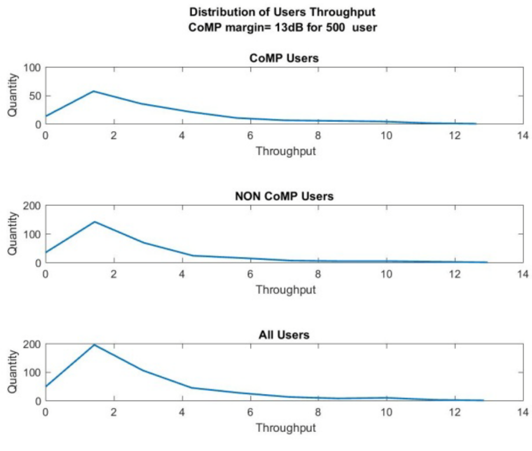


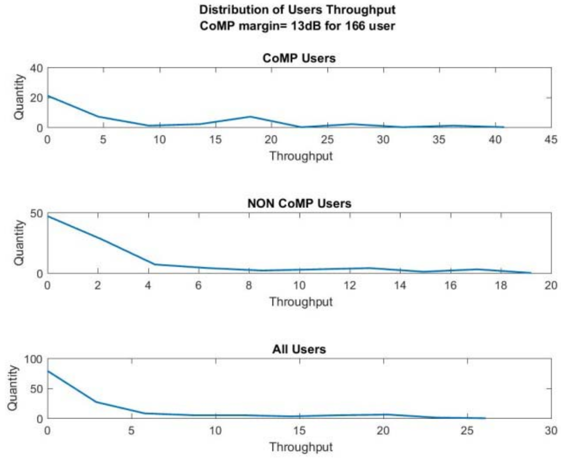

Distribution of Users Throughput
CoMP margin= 10dB for 500 user
CoMP Users
NON CoMP Users
All Users
Quantity
Throughput

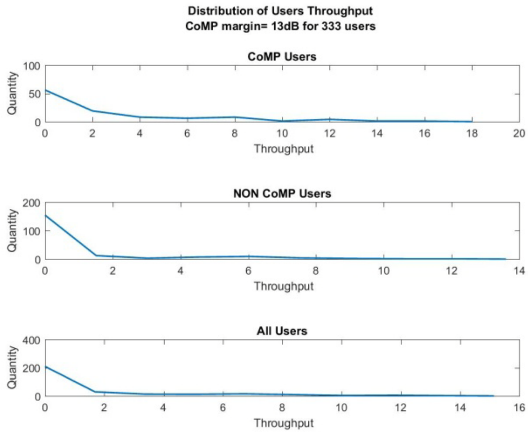

Distribution of Users Throughput
CoMP margin= 10dB for 166 user
CoMP Users
NON CoMP Users
All Users
Quantity
Throughput

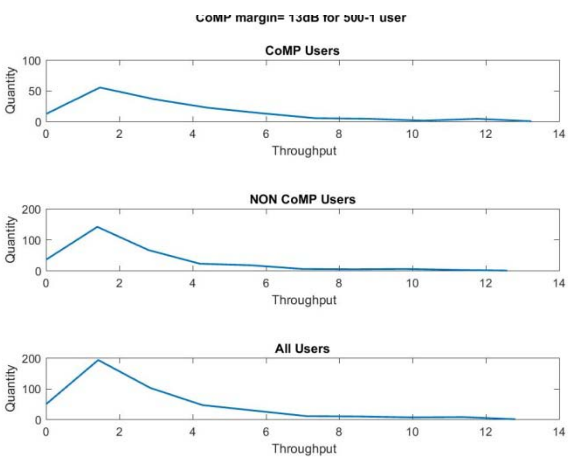

Distribution of Users Throughput
CoMP margin= 10dB for 333 users
CoMP Users
NON CoMP Users
All Users
Quantity
Throughput


Distribution of Users Throughput
CoMP margin= 10dB for 500-1 user
CoMP Users
NON CoMP Users
All Users
Quantity
Throughput


Distribution of Users Throughput
CoMP margin= 13dB for 500 user
CoMP Users
NON CoMP Users
All Users
Quantity
Throughput


Distribution of Users Throughput
CoMP margin= 13dB for 166 user
CoMP Users
NON CoMP Users
All Users
Quantity
Throughput


Distribution of Users Throughput
CoMP margin= 13dB for 333 users
CoMP Users
NON CoMP Users
All Users
Quantity
Throughput


CoMP Users
NON CoMP Users
All Users
Quantity
Throughput

Chapter 5

Definitions

- **CoMP Margin and Bias**: Coordinated multipoint should happen when the received power of the CRP cell is within the certain range of the serving cell. This condition implies the cell edge condition where, received RSRPs from two cells, serving and CRP are in the same order. This region is exactly the region of interest where CoMP has the highest efficiency. Intuitively, the higher the CoMP margin, the larger the number of UEs who satisfy the condition to become CoMP users. The CoMP condition can be seen as follows:

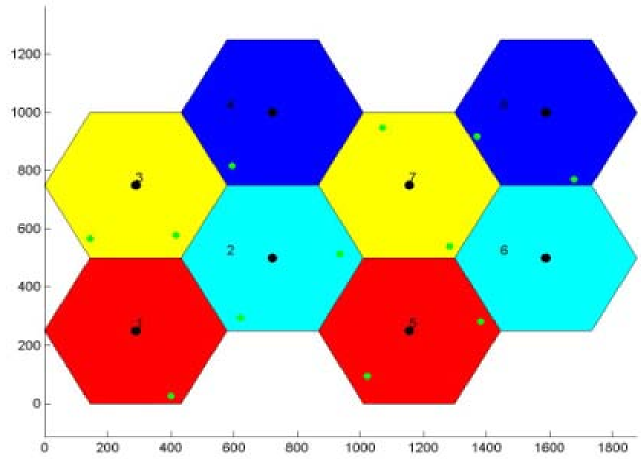
$$RSRP_{CRP\ cell} > RSRP_{serving} - CoMPMargin_{dB}$$

  Cell selection for every UE aims at maximizing RSRP, although a constant bias (Selectable Value) is added to the nominal small cell RSRP. This procedure, known as Cell Range Expansion (CRE), helps compensating for the power gap between macro and small cells, thus offloading UEs from the former to the latter. The CRE power bias is applied to both service cell selections as well as to the selection of Coordinated Reception Points for CoMP. In order to reduce the complexity of the simulation, the CRE bias at all small-cell eNBs are equal and static during the simulation.

- **CoMP Pool Percentage-CPP** This parameter defines the portion of the resources which should be allocated to user connecting to eNB as a CRP cell for each eNB. CPP value for each eNB is variable during the simulation. The aim of article if suggest a solution to better select a value of CPP. In our algorithm CPP value is indeed based on the number of physical resource blocks reserves as frequency resources for CRP users. Lowest value of CPP is equal to 0 percent and maximum possible value is 50 percent. It is needed to mention that the in case of absence of users connection to a particular eNB as Serving or CRP , CPP value for that particular eNB set to 100% and 0% respectively.

- **Cluster:** Contains 4 hexagons centralized with a Macro-cell and 6 Micro-cell randomly distributed in the cluster. Each cluster has a scheduler entity to decide about connections and apply the algorithm. Figure below (Fig.1) illustrates two adjacent clusters.(green point indicate small cells)

- **Frequency Reuse**
  - ✓ All the eNBs are using the whole spectrum (10 MHz)
  - ✓ Adjacent eNBs are using different Spectrum band (CPP portion) for their CoMP users (cell edge users)
  - ✓ Frequency Reuse Factor of 4
  - ✓ Cells with sufficiently large distance can use the same frequency band.



General Description

Since, in our algorithm, the Throughput value for CoMP users and relative quality of service in terms of throughput is concerned; in the first phase CoMP users and NON CoMP user are categorized into two different classes of users. This procedure is carried out by the scheduler entity by following steps:

1. Form a two dimensional matrix which the rows indicate the users and the columns are representative of the cell numbers. Each element of this matrix illustrates the RSRP for each user (location in each row) associated with all the eNBs (cells) locating in the columns .(User base RSRP Matrix)
2. Fill the matrix with the RSRP associated to each pair of Cell number and user.
3. According to the User Base RSRP matrix, the algorithm chooses the *Best eNB* to play the role of *Serving cell* for each particular user.
4. Since in our algorithm CoMP functionality in active within a clusters, based on the configuration of the clusters, Scheduler entity defines the cluster associated to each user. Therefore from this point the CoMP decisions and scheduling is done for cells belong to that particular cluster.
5. The algorithm refines the *User base RSRP Matrix* to the matrix, in this new matrix eNBs only locating within the same cluster of *Serving Cell* have a valid value of RSRP, therefore the CoMP cell selection is confined within clusters.(Refined User base RSRP Matrix)
6. We sort the associated eNBs from same cluster for each user (each row) in decreasing manner. Consequently, for each user, *Serving cell* is always locating in first column and next columns are dedicated to reserved cell to contribute in CoMP process or namely *Potential Neighbors or CRP.*
7. Depends on the selected *Handover Margin* and *CoMP margin*, scheduler entity automatically selects the Active Neighbors named *CoMP Reception Point (CRP)* which can contribute in CoMP process for each user.

In this point the algorithm successfully form the matrix indicating the proper *Serving and Neighbor cells (CRP cells)* for each user (Users Base CoMP Matrix). Since the users with no CRP cell has just one cell as serving, in the mentioned matrix, Users Base CoMP Matrix, users with No associated element (cell) in second column categorized as *NoN-CoMP users*. Other users have more than one associated cells as serving and neighbor are categorized as *CoMP users*.

In short, Uplink CoMP relies on measurements reported by the UE through standard signaling channels, comparing the received power of the candidate CoMP Reception Point (CRP) cell and that of the serving cell. If the RSRP of the CRP meets the CoMP margin (measured in dB), condition then the candidate is selected as CRP. Clearly, the higher the CoMP margin, the If more than one cell satisfies the condition, the CRP are selected in increasing order of RSRP values, up to 3 CRP cells.

Please note that, since back-haul conditions are not modeled in our simulation, the CoMP margin value does not depend on the network load. Likewise, the CoMP margin does not depend on cell or cluster sizes.

Resource allocation and throughput computation

Our performance evaluation focuses on the allocation of radio resources among CoMP and non-CoMP users. At a system level, we assume that frequencies are allocated to eNBs according to the Fractional Frequency Planning, with a frequency reuse factor of 4. We use a co-channel frequency deployment; hence small cells use the same frequency band that macro cells use. Our algorithm model clearly accounts, through equation (Eq.1) below for any possible interference among users in different cells, who are allocated the same PRBs.

$$SINR = \frac{P_{RX}(PRB)}{P_{noise} + \sum_{u \in S} P_{RX}(u)}$$

Where *S* is a set of UEs, which the same PRB is dedicated to them for their uplink communication.

Within a cell, we simulate different resource splits. Every cell sets aside a fraction of resources, i.e., of Physical Resource Blocks (PRBs), for UEs that transmit to it as their serving cell. These resources are typically allocated to UEs close to the cell core. The remaining fraction of PRBs is reserved for UEs that use the cell as CRP and are thus close to the edge. We identify the latter fraction, i.e., the portion of PRBs that are reserved for CoMP as CoMP Pool Percentage (CPP). In each instance, the value of CPP is identical across all cells in whole network or cluster involved in CoMP (which, as we have seen, depends on the scenario). By definition, CPP is 0 for cells that do not participate in CoMP. We also point out that if the CPP of a cell is not completely allocated for lack of CoMP users, its PRBs are available to be scheduled for non-CoMP users.

Resources are then allocated to UE for their uplink communication based on the Proportional Fair (PF) scheduling policy. The PF policy combines high throughput proportional fairness among all UEs by giving instantaneous priority to UEs with a high-quality channel rate and a low average service rate.
The user uplink throughput is computed (by Shannon formula) from the number of PRBs that the scheduler allocates to each user, depending on the cell it communicates with (either serving or CRP) and the associated SINR calculated above. It should be mentioned that the effect of *fast fading* is also considered in the obtained results.

As a parallel hint for traffic model, it should be mentioned that, we choose the most aggressive model in term of demanding traffic to upload in order to better observe and prove the functionality of the algorithm. In our model, UEs are assumed to be in saturation, i.e., they always have data traffic to upload and greedily use all the resources they are allocated by the eNB.

Algorithm

One of the main improvements compared to prior arts is the Dynamic CPP Decision Algorithm - DCD Algorithm. This technique allows the scheduler to modify the CPP value for a next decision time window. Decision time window is a limited time period (100 TTI) which the network utilizes a constant value of CPP for all eNBs within a cluster. In other words, DCD algorithm, selects the proper CPP value for next decision time window for a whole network or each cluster in parallel. The algorithm basically has 2 indexes (between 0 and 1) as internal inputs. Scheduler uses these indexes to filter the proper users to be proceeding with the CPP decision process.
These indexes, (Bottom Throughput list index) for CoMP users and NON-CoMP users, are described in details in next paragraphs.

Dynamic CPP Decision - DCD

For the First decision time window algorithm automatically selects the CPP equal to 2% as an initial point. At the end of each decision time window, scheduler executes and calculates various parameters in order to select the best CPP for the next run. Reference point for scheduler to modify the CPP is achieved by preceding the tasks as follows:

- Scheduler computes the throughput for users who are using CoMP (CoMP users) and users do not access to CoMP functionality (Non-CoMP user) independently and sort them in two lists in terms of throughput.
- During the throughput calculation process of users, small quantity of users who has the high value of throughput. These users acquire very high throughput compared to others because of their special location or connection type. These kinds of users, in our algorithm, make other users to have low value of index as well as made singularity. Since users have a truncated normal distribution shape in terms of throughput, Algorithm filters the users according to their throughput to eliminate the users with unbounded value of throughput. The cutoff value for throughput is equal to mean plus standard deviation of obtained throughputs.

- Scheduler entity normalizes the filtered user's throughputs to 0-1 range, in both categories of CoMP and NON-CoMP users, according to the highest filtered achieved throughput.
  Numerical example is provided, in table 1, for better understanding the concept:

Sorted Throughput Vector Mbps	1	2	4	6	7	9	12	13	15	20	25	100
Associated indexes	0	0.04	0.12	0.2	0.24	0.33	0.45	0.5	0.58	0.79	1	Filtered out

As an instance, if the index = 0.25, first five users meet the condition so the average of their throughput would be: 20 / 5 = 4 Mbps.

- For CoMP and NON CoMP user the algorithm addresses two independent "Indexes" so the comparison over the average throughputs for the selected index is done in the "Feedback and Comparator" section (Fig.4) in scheduler entity. While in the same place CPP value is selected with feedback process. The scheduler is scheduling the recourses according to the CPP value for next 100 milliseconds. Average of Calculated throughputs would be the first step of the mentioned process for the next round of decision and calculation.

- Based on Bottom Throughput list indexes for CoMP users and NON-CoMP users, scheduler filters bottom users in throughput list with lower indexes.
- The average throughput over decision time window (100 TTI) for filtered users, in both CoMP and NON-CoMP categories, is calculated.
- The algorithm modifies the CPP value according to the comparison of two averages by proceeding of one of the options described as follows:

1. CoMP filtered users average is less that NoN-CoMP filtered user's average

Since this condition implies the situation which CoMP users suffer from shortage of resources compared to NON-CoMP users. DSD Algorithm decides to increase the CPP. If the difference between averages of throughput is notable, DSD apply the accelerated increment and add 4% to CPP value. Where in normal situations which the gap between the obtained averages is lower, CPP value is increased by 2%.

Please note that since we set 10Mhz and uplink connection bandwidth and accordingly 50 pysical resource blocks (RPB) increament steps are 2% and 4% respectively. Minimum increament step is always equal to one over the number fo PRBs multiplied by 100 (in percent) and second coefficient equals 2 time sof the first step. For instance the incrametn steps would be 1% and 2% for 20Mhz of uplink frequency bandwidth.

2. CoMP filtered users average is more than NoN-CoMP filtered user's average

New value of CPP is obtained by the equation (Eq. 2) below.

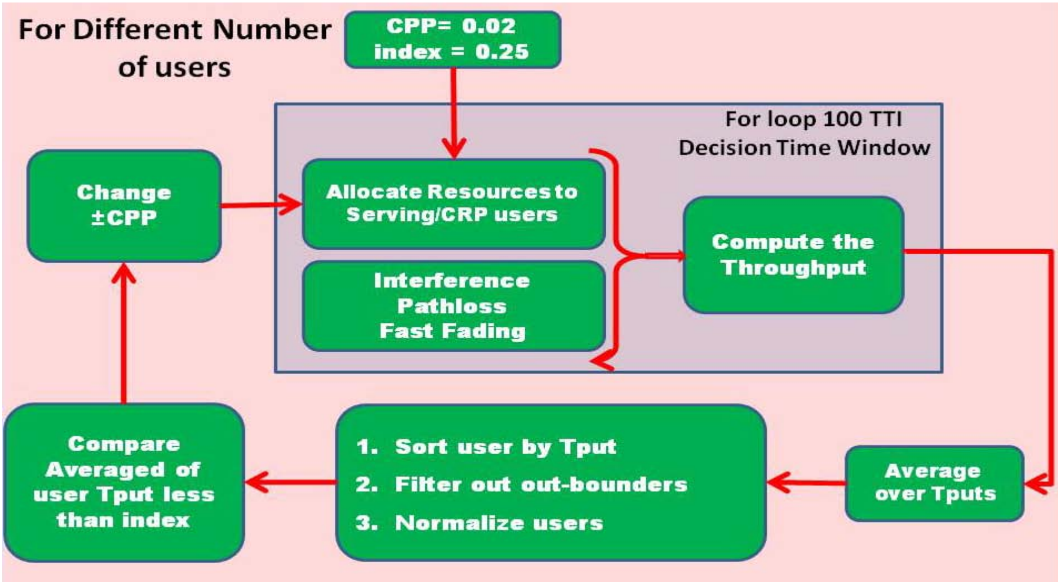
$$CPP_{Next} = 0.02 * \left\lfloor (CPP_{Now} * 50 * \frac{Tput_{NonComP}}{Tput_{ComP}}) + 1 \right\rfloor$$

Please note that since we set 10Mhz and uplink connection bandwidth and accordingly 50 pysical resource blocks (RPB) the main coefficients are 0.02 and 50 respectively. First coefficient is always equal to one over the number fo PRBs and second coefficient equals to exact number of PRBs. For instance the coefficients would be 0.01 and 100 for 20Mhz of uplink frequency bandwidth.

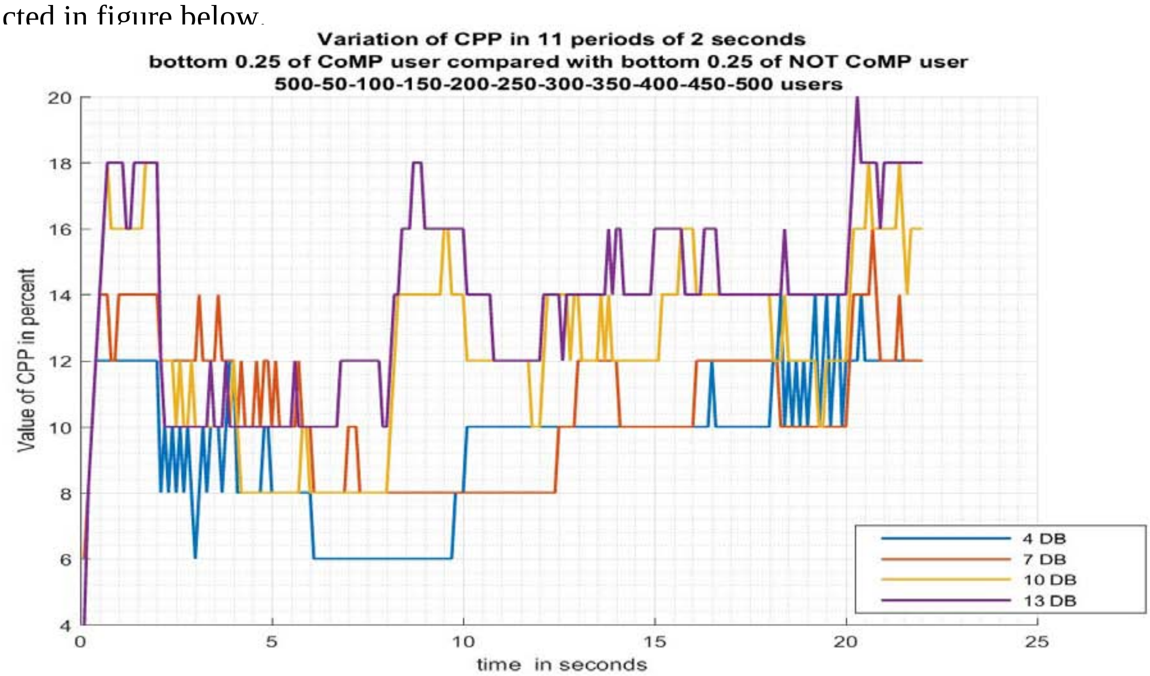
3. CoMP filters users average is equal to NoN-CoMP filtered users' average

System continues with the same CPP value.

Algorithm General flow chart is demonstrated in figure below.



It should mention that CPP value is uniquely selected for the whole network or also within a cluster, likewise the same process will be in progress for the next CPP decision time. As an example modification of the CPP during the simulation for various numbers of users and different CoMP margin values, for test reason, is depicted in figure below.



Algorithm is also illustrated by figure below:

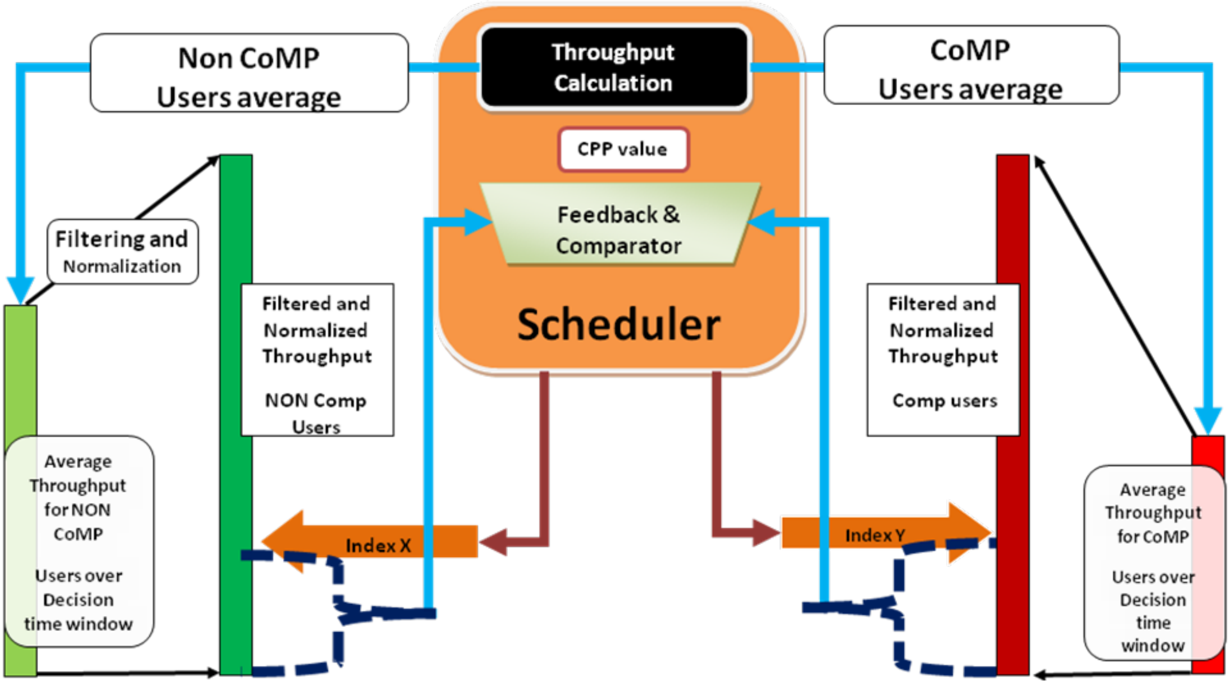
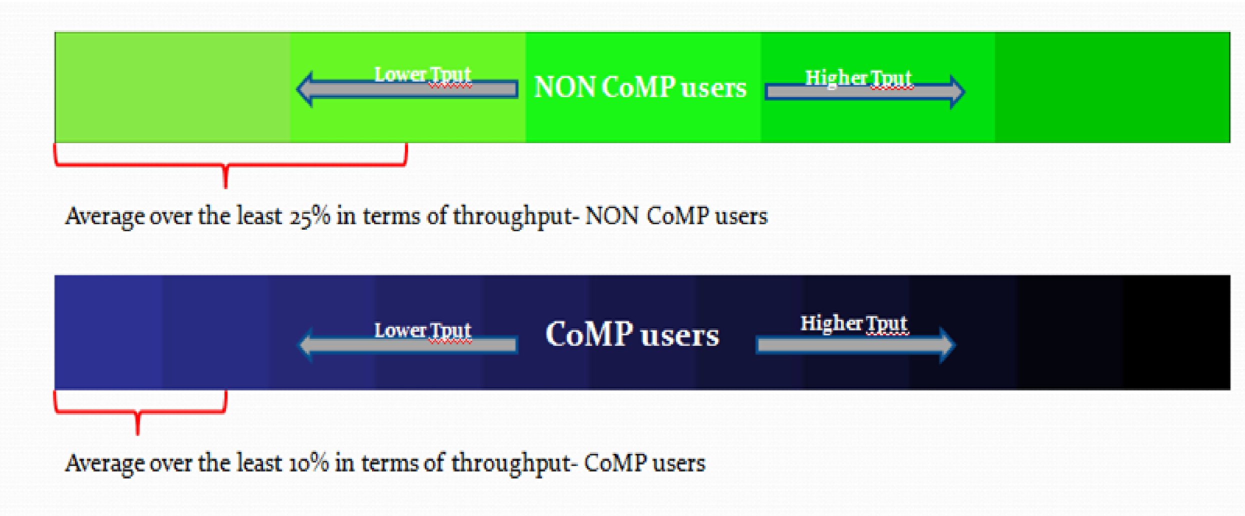


Figure below illustrated the normalized user's selection by throughput overview.

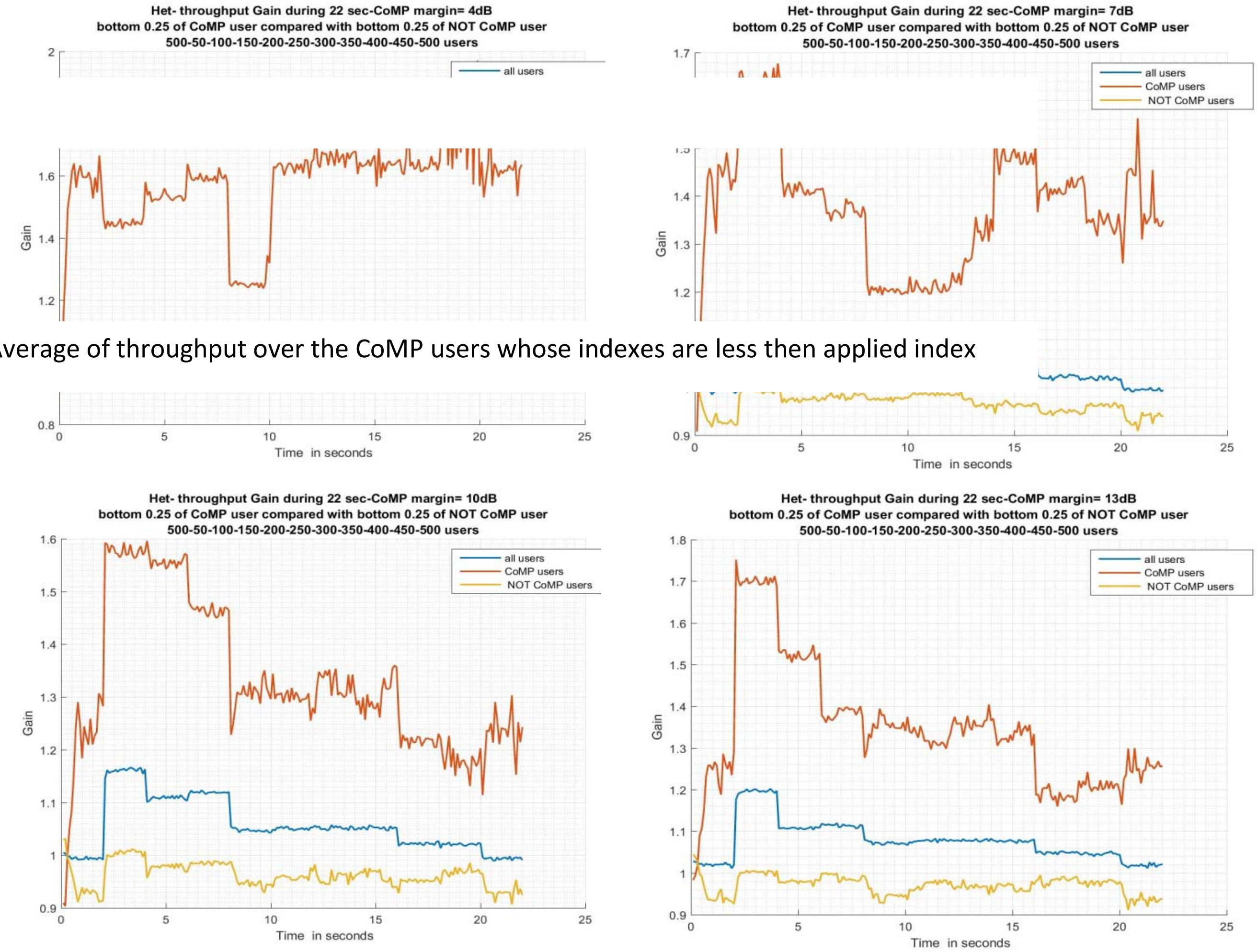


Results

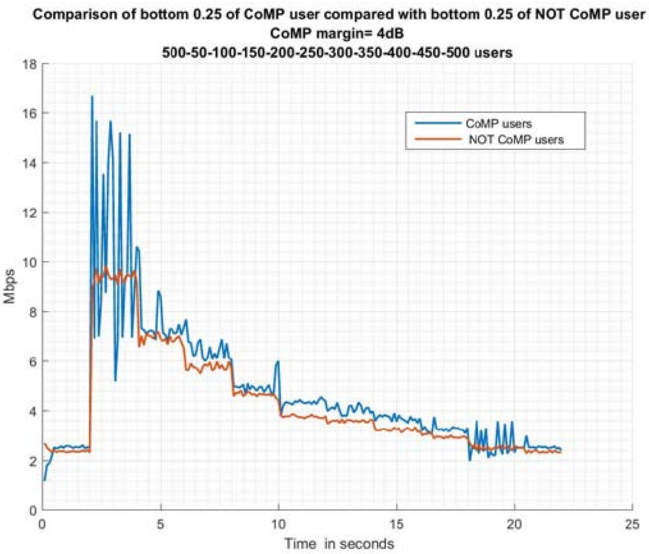
As a very quick result review of the simulation of the algorithm, in different scenarios in terms of number of users and different CoMP margins, it could be seen the average gain of 20% or 25% in different scenarios for CoMP users. All these results are obtained in the conditions that the network gain for whole network's users shows also improvement by average of 5% and the system did not experienced a negative gain during the simulation period. It is needed to mention that these results are based on fully loaded network situation which all the users' traffic model is modeled by "full buffer" scenario. Fast fading effect is also considered to obtain the results

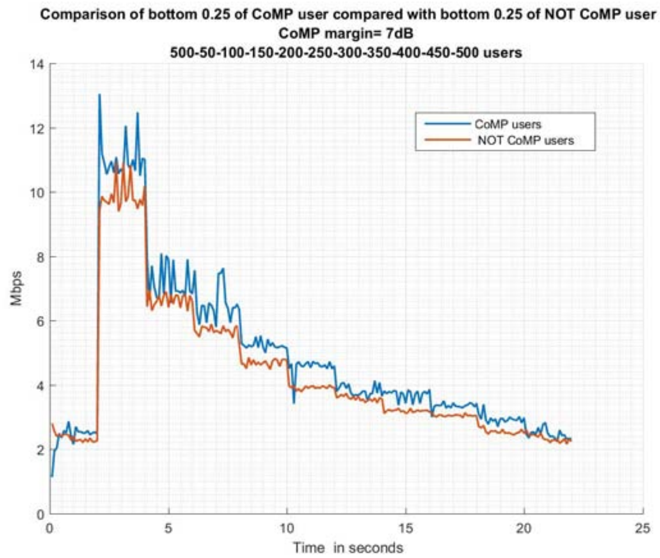
Please note that the results are obtained for different number of randomly selected users (500, 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500) in a similar network layer of combination of two clusters. Applied CoMP margin values are 4, 7, 10 and 13 dB respectively. Mentioned index values for CoMP and Non-CoMP users are both set to 0.25.

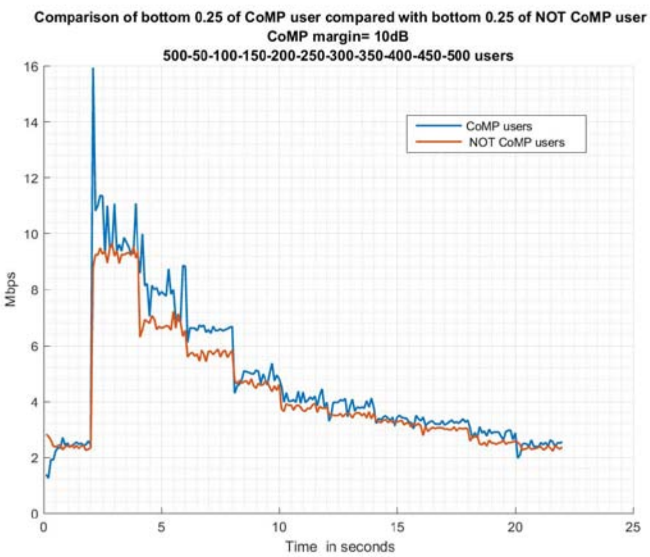
In below figure average Throughput Gain for CoMP, Non-CoMP and all users is demonstrated separately in different scenarios.

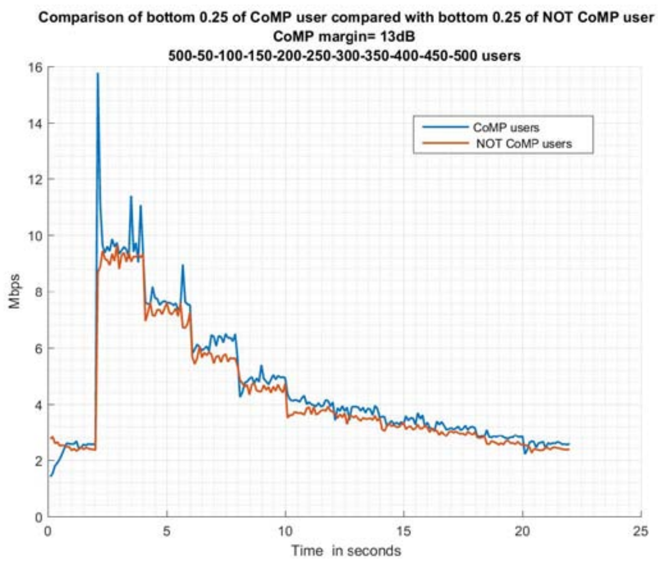


In Figures below the behavior of the algorithm, where the comparison process is taking place inside the algorithm, is directly shown for various CoMP margins.

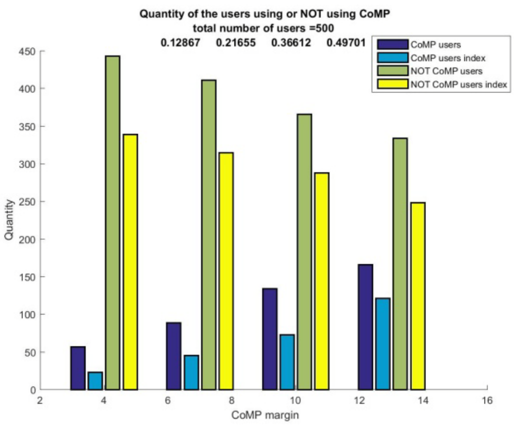








of after filtering , normalization and index base selection is shown for 500 and 200 users' cases.



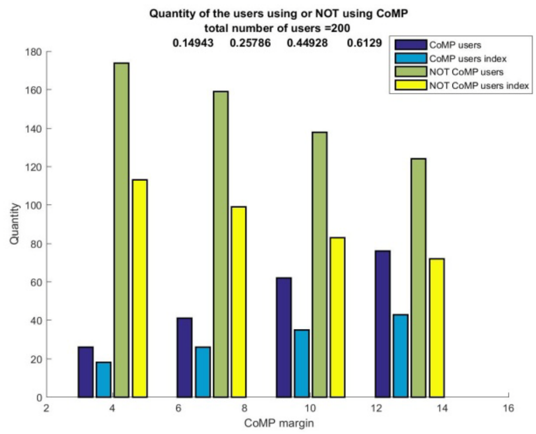
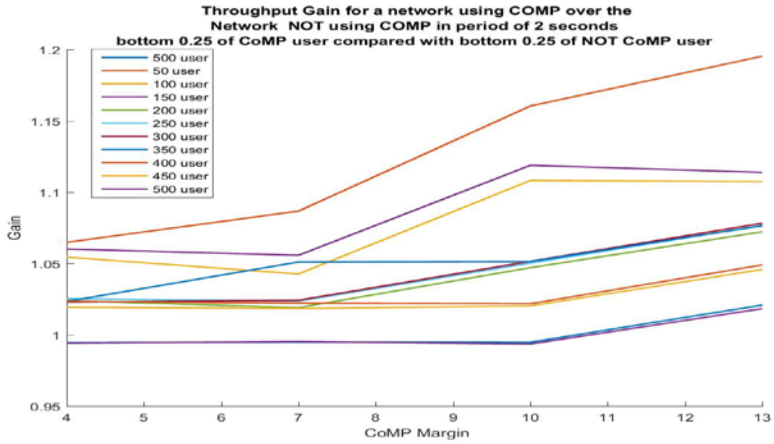
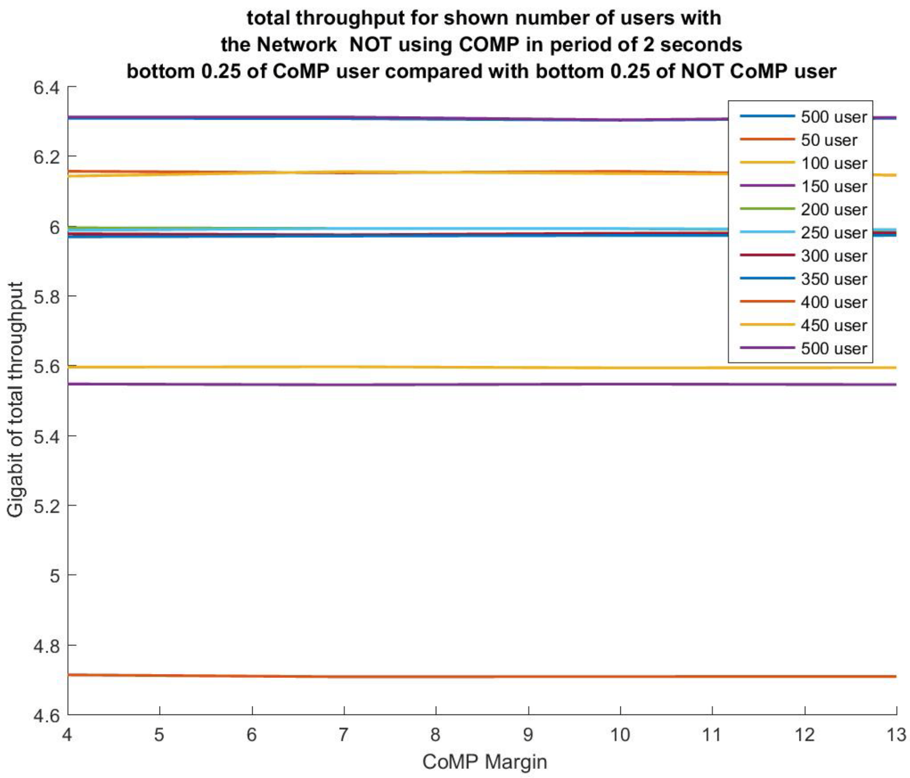


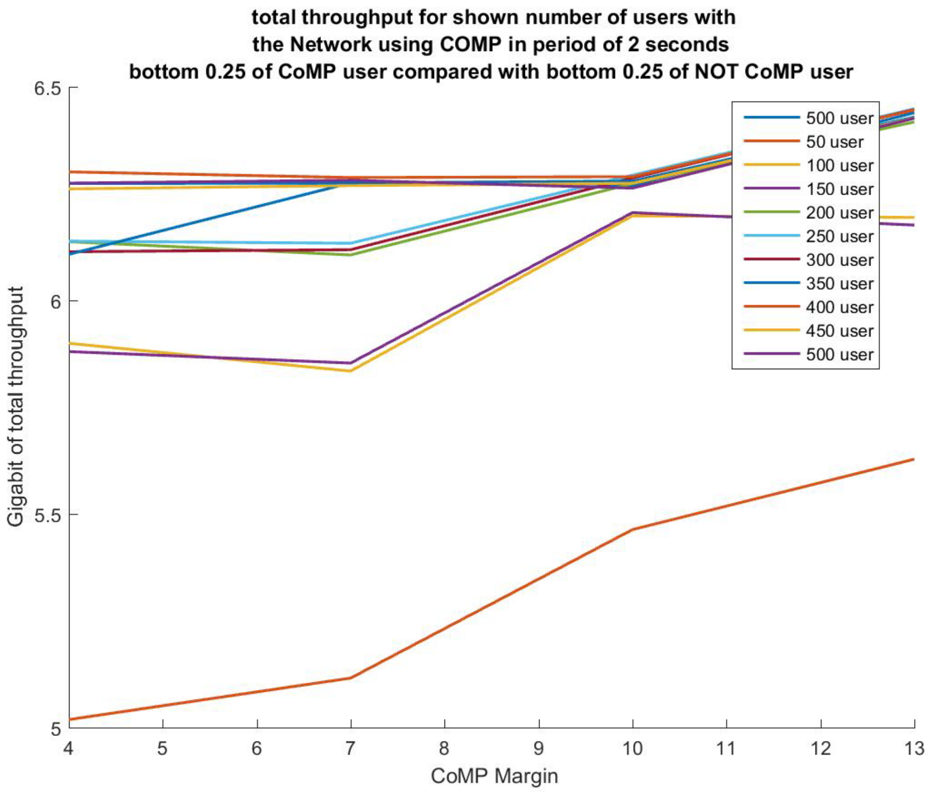
Figure below shows the achieved gain for whole network users for different populations of users based on various values of CoMP margin. (Value are obtained based on mentioned simulation)



Supplementary information and settings in simulations (Table.2)

Used Settings or Information	*Applied Value, Formula or setting*
Macro cell locations and distribution	Hexagonal Distribution with inter-cell distance = 500 m
Micro cell locations and distribution	Random location mostly on cell edges
Number of Clusters	2 adjacent Clusters
Hot Spot Radios (Micro-cells)	50 meter
Number of cells in Clusters	12 Macro cell and 6 Micro cell per Cluster
Number of users	500, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500
Applied Scenarios	Heterogeneous
Handover threshold	3 dB
CRE Power Bias	6 dB
Number of PRBs	50 Physical Resource Blocks (Uplink)
Noise Power	-174 dBm/Hz
Uplink Bandwidth	10 MHz
PRB Bandwidth	180 kHz
CoMP Margin Values	4, 7, 10, 13 dB
Max. Number of CRPs	3
User Transmit Power	20 dBm
Path-loss Model	$Pathloss_{Macro} = 128 + 37.6 \times \log(\text{distance})$ $Pathloss_{Micro} = 140 + 36.7 \times \log(\text{distance})$
Users Velocity Model	40% fixed - 30% low speed - 30% high speed
Traffic Profile	Full Buffer
Macro-cell Antenna Radiation Pattern	3GPP standard Model
Fast Fading	Rayleigh


total throughput for shown number of users with
the Network NOT using COMP in period of 2 seconds
bottom 0.25 of CoMP user compared with bottom 0.25 of NOT CoMP user
Gigabit of total throughput
CoMP Margin
500 user
50 user
100 user
150 user
200 user
250 user
300 user
350 user
400 user
450 user
500 user


total throughput for shown number of users with
the Network using COMP in period of 2 seconds
bottom 0.25 of CoMP user compared with bottom 0.25 of NOT CoMP user
Gigabit of total throughput
CoMP Margin
500 user
50 user
100 user
150 user
200 user
250 user
300 user
350 user
400 user
450 user
500 user

General aspects and alternatives of an algorithm

- ✓ The "Resource" parameter is a generalized representative of the useful resource for any kind of connection between any kinds of subscriber and access points. Similarly the algorithm is also applicable for resources in terms of "Time" or etc.

- ✓ "CPP" term definition is not limited to frequency regime; it could be translated or mapped to time or other resources to be scheduled in networks.

- ✓ Recent "Resource Allocation algorithm" is also applicable to all kind of wireless networks which one subscriber is connected to more than one service provider or access points.

- ✓ This algorithm for scheduling the resources can also be used in downlink CoMP scenario and connections in cellular or other wireless networks.

- ✓ Mentioned Resource scheduling algorithm is applicable to different scenarios in term of deployments in cellular networks. According to the cellular network settings, the CoMP functionality maybe activated just for some type of the cells. For example, one of the scenarios, mentioned in following, may put some restrictions for CRP cells. But, algorithm is completely transparent to the selected connection scenario.

  - **Inter scenario:** CoMP is enabled just for one of the two cells of the same Macro eNB where the serving cell is located.
  - **Inter**: CoMP is enabled for cells from any macro eNB, not restricted to cells of the serving eNB. Small cells cannot be used for CoMP.
  - **Small**: Although any cell can be a serving cell, only small cells can be CRP.
  - **Het**: No restrictions in the roles of serving and CRP.
- ✓ The "Micro cell" term is just a representative of low power eNB or access point. In general and also in heterogeneous deployment, CoMP and mentioned algorithm can be functionalized in parallel for all kind of eNBs (Macro-cells, Micro-cells, Pico-cells and Femto-cells)

- ✓ In the simulation, we demonstrate the results calculated in terms of throughput, generally the calculation or the normalized values could be in terms of other functionality or properties.

- ✓ Different optimization algorithms could be integrated with or mapped on described scheduling algorithm in order to choose the proper indexes for CoMP and Non-CoMP users independently.

- ✓ As a scheduler, we proposed “Proportional Fairness scheduler” to be implemented in CPP and complementary part of resources. Generally other general or specific algorithm and coefficients (like Round-Robin or etc) can be substituted and applied.

- ✓ Maximum preferable (not restrict) value for CPP is based on the Factor of frequency reuse. For instance, with frequency reuse of factor 4, best performance in terms of interference in obtained for CPP up to 0.25. In other words, minimum interference in expected when maximum of one fourth of the resources is dedicated to CoMP users.

- ✓ CPP is just a representative of the portion and quantity of the resources dedicated to CoMP-users. Frequency, and generally resources, distribution is an optional choice while conditions are met.

- ✓ Results are based on “full buffer” traffic model. Other traffic models can be applied and tested.

- ✓ We applied Clustering property for the scheduling model. The algorithm is also functional for network layer without clustering option. In this case, scheduler entity has to be synchronized and matched for the whole network or a part of it. Mentioned changes in the model needs a lot of computations, power, and it is according to more complexity and latency.

- ✓ Coefficients in Equation.2 and CPP increment section (CPP decision) depend on the system bandwidth. For other bandwidth options, different coefficients have to be applied. (see Equation.2 notes)

- ✓ Decision Time Widows length is set to 100 TTI (100ms). According to scenario and different settings it could set to different values.

- ✓ In filtering process of the users in terms of their throughput, the algorithm suggested certain value of “mean + variance” of the users throughput. Based on the users’ distribution shape and algorithm, other filtering options can be added or substituted to the procedure.

- ✓ The algorithm is completely transparent to other simulation option and settings like path-loss model, fast fading, channel properties and network layer specifications like eNB distribution, number of users, associated velocities and transmitted power, selected CoMP margin, handover margin, bias value and etc.

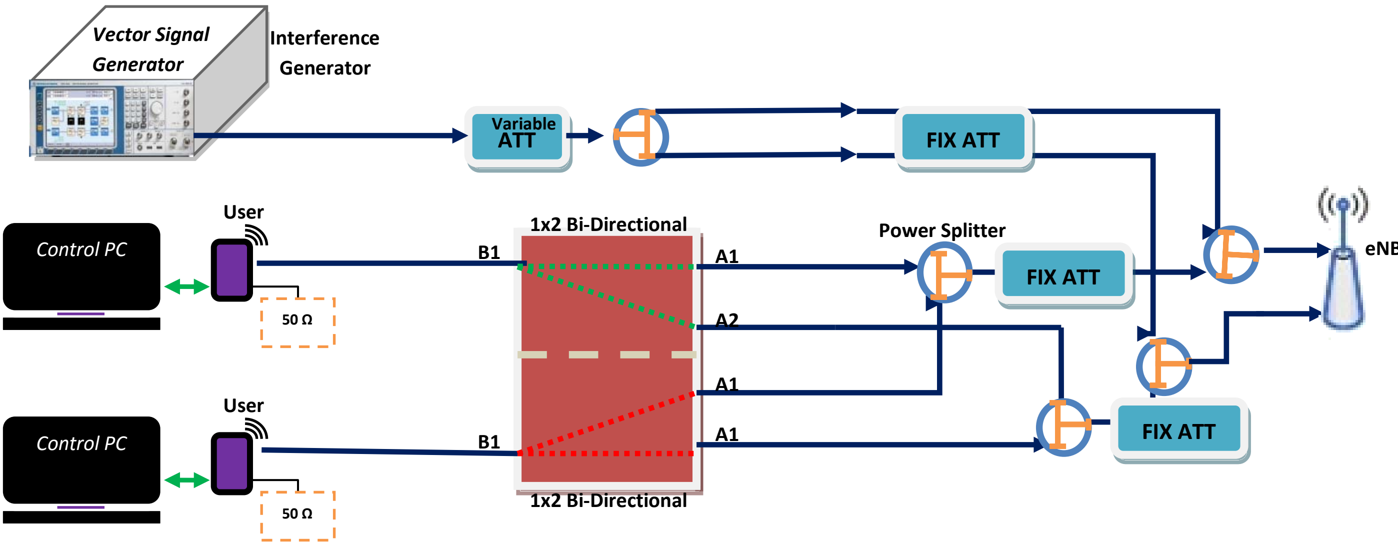
- ✓ Interference is highly reduced in cluster level of the cellular network by application of CPP and coordinated scheduling algorithm. According to the necessity, other interference techniques are compatible with and applicable to system.

Chapter 6 | Appendixes

Appendix 1	Throughput evaluation of different scheduling scenarios Lab Test
Appendix 2	Interference Aware Scheduling (IAS) Lab Test
Appendix 3	Interference Rejection Combining –IRC test Lab Test
Appendix 4	Overall Network Structure for Test of IRC Lab Test
Appendix 5	Lab Report on CoMP functionality procedure and test
Appendix 6	A System-level Assessment of Uplink CoMP in LTE-A Heterogeneous Networks – Conference Paper
Appendix 7	Prior Art
Appendix 8	Submitted Patent

Throughput evaluation of different scheduling scenarios

The following chapter is dedicated to the test of the uplink throughout parameter of two different UEs in the different scenarios according to the selected scheduling algorithm, movement profile, and model of interference and associated RB to each user.



Interference model:

For center frequency of 2.6 GHz 2535-2550 MHz, we adjust the bandwidth of the power of interference equal to 4MHz and 0 dBm respectively. The sweeping time over the whole bandwidth of the generated AWGN by signal generator is different in two cases of the test. In real environment, interferes are other UEs and consequently eNB or generally LTE network has control over them. But in this case, which is more aggressive in terms of interference LTE network does not have any control over the interfere signals which are transmitted by virtual users (signal generator)

Sweeping time:

- 100 ms
- 10 ms

Associated RB:

In eNB there is an adjustment for RB associated to each user, The total value for RB in bandwidth of 15Mhz is equal to 75, but by dedication 3 of them to signaling the remaining useful ones are 72.by changing (decreasing) number of associated RBs to each user we consequently add some degree of freedom to scheduler to choose a best RB to dedicate to each user in terms of interference rejection. In this test, we evaluated the uplink throughput in different associated RB equal to 12 and 24 RB per each user. One should keep in mind that there are totally two active users involved in this test.

RB in this case is equal to

- 12 RB
- 24 RB

Movement Profiles:

As long as the emulation of movement in real environment is concerned we used standard 3GPP E.V.A. and E.P.A. standards in low correlation condition to perform the test. Therefore we used 3GPP movement profiles in order to perform a standard test

- EPA3 - low correlation
- EVA30 - low correlation

Scheduling algorithm

In this step we performed a test for different scheduling parameters such as follows:

- **CUS**: Channel Un-ware Scheduler
- **CAS with SRS control over power** : Channel Aware Scheduler with control over SRS power
- **CAS with SRS**, **no power control**: Channel Un-aware Scheduler with control over SRS power
- **IAS**: Interference Aware Scheduler

Test procedure:

In this part of the test, we change the interference power in the fixed received useful signal power in observe the system response. System scheduler would automatically dedicate proper RBs to each user in order to reach the highest throughput. The values of the attenuation associated to user signal power are shown in the table below:

RSRP	eNB Tx power Ref. Sig.	User Tx power	User power @ F.S. input	F.S. Power toward eNB	eNB power @ F.S. input	F.S. Power toward User
-85	30.6 dBm	21 dBm	15 dBm	**-42**	0 dBm	**-52**
-90	30.6	21	15	**-47**	0	**-57**
-95	30.6	21	15	**-52**	0	**-62**
-100	30.6	21	15	**-57**	0	**-67**
-105	30.6	21	15	**-62**	0	**-72**
-110	30.6	21	15	**-67**	0	**-77**

For each of the RSRP above we changed the value of the received power for interference by changing the attenuation in the path of interference, table below shows the values:

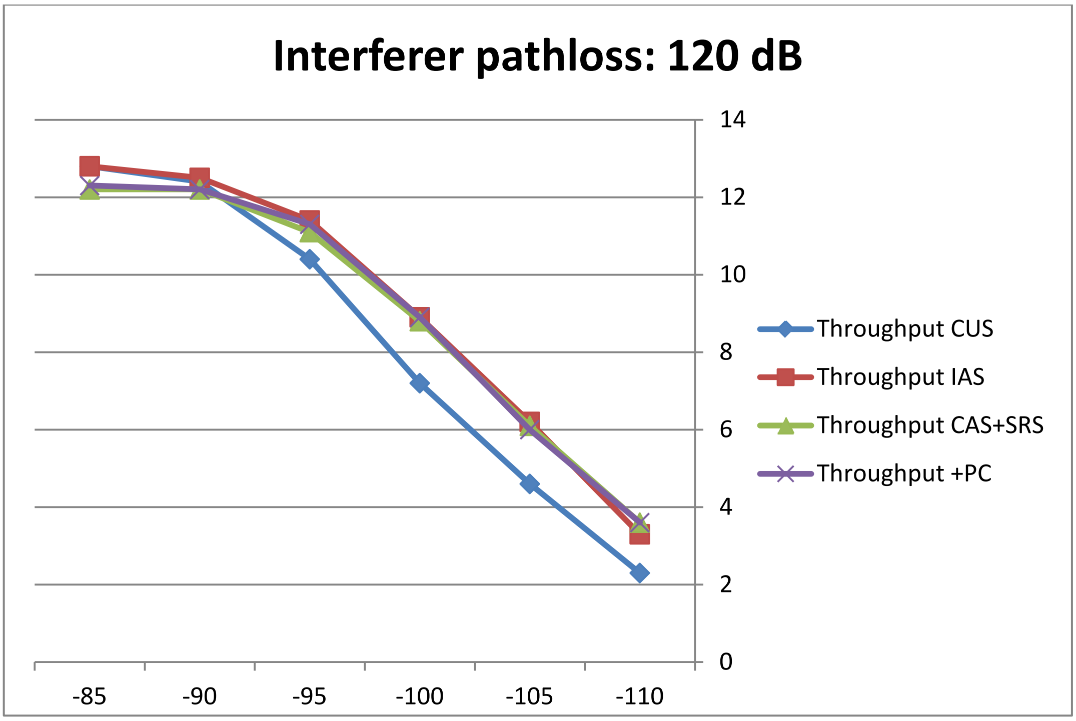
Note : Fix Path attenuation in this case = 61 dB

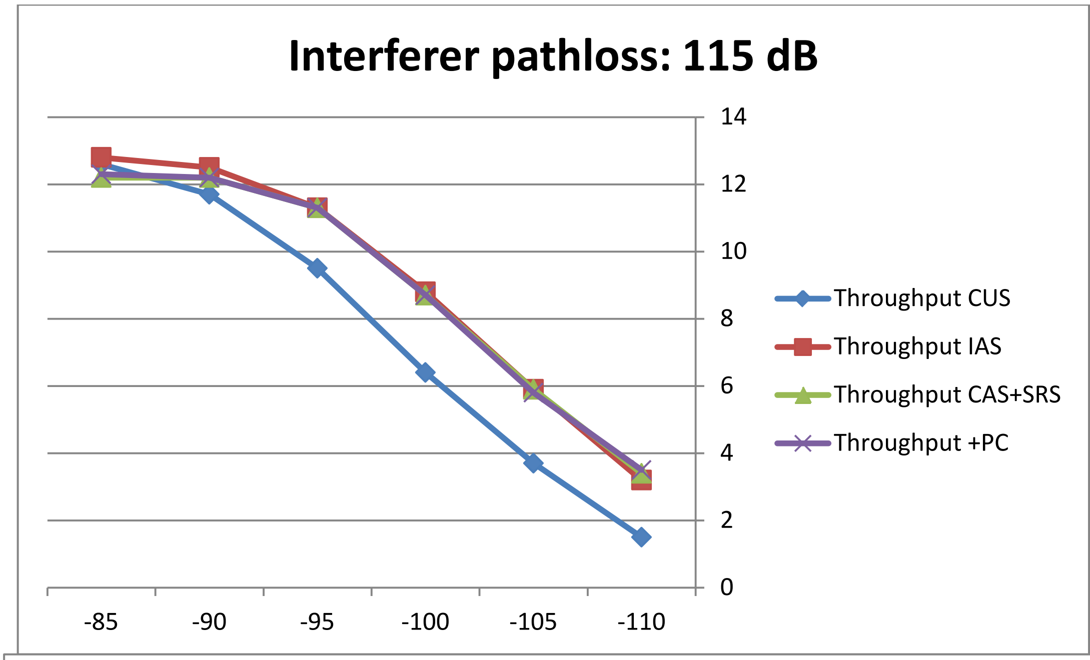
We evaluated the Uplink throughout different scenarios in term of received useful power and interference. The values of the attenuator in the path of interference are

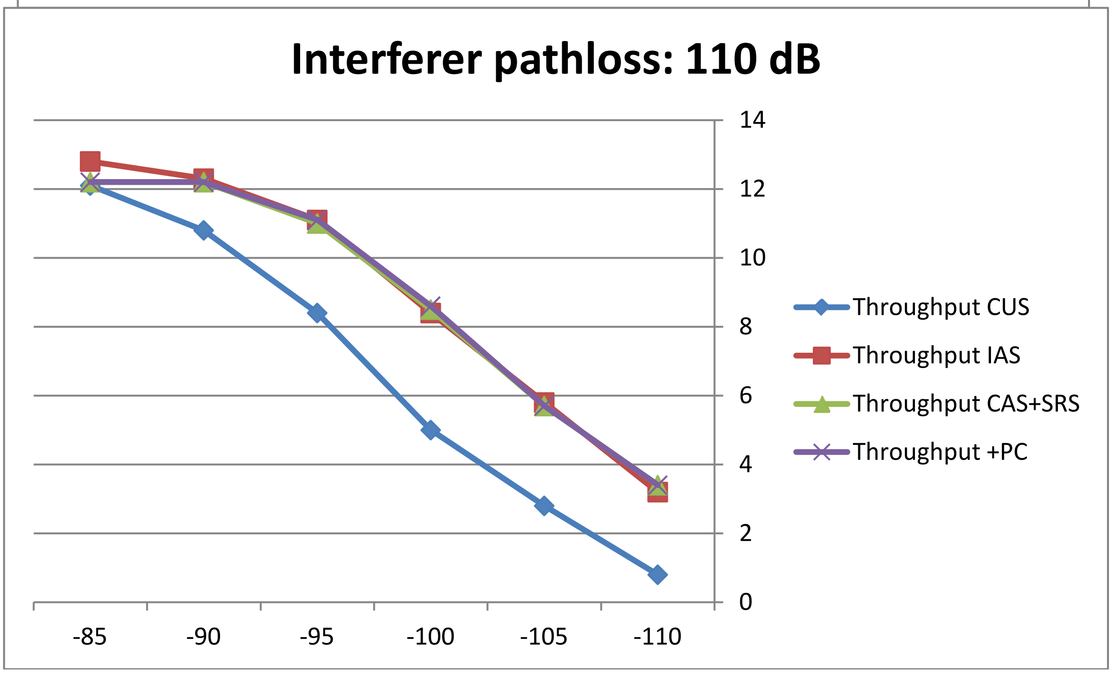
eNB Tx Power dBm	User dBm	RSRP	Total loss dB	Variable Attenuator dB	Sig. Gen. Tx power	Received Power	Int.
30	-60		90	**29**	0	-90	
30	-65		95	**34**	0	-95	
30	-80		110	**49**	0	-110	

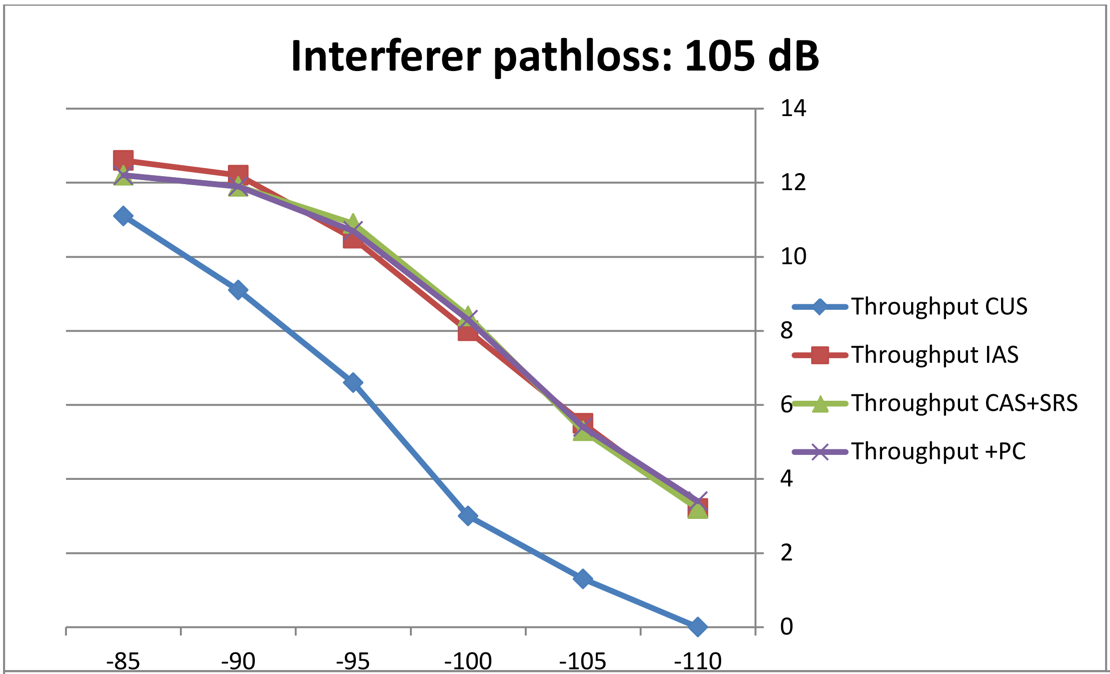
shown in the above table.

Following results and graphs show the value of obtained throughput in different scenarios according to different values of interference.

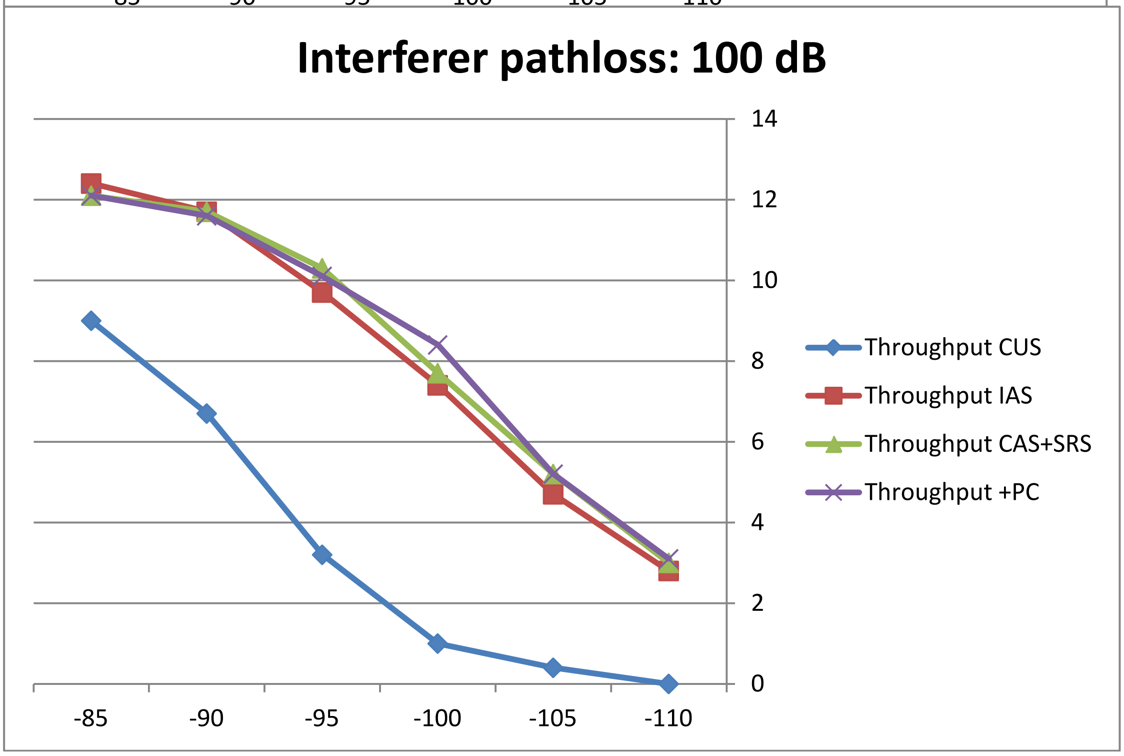



Interferer pathloss: 115 dB
14
12
10
8
6
4
2
0
-85
-90
-95
-100
-105
-110
Throughput CUS
Throughput IAS
Throughput CAS+SRS
Throughput +PC

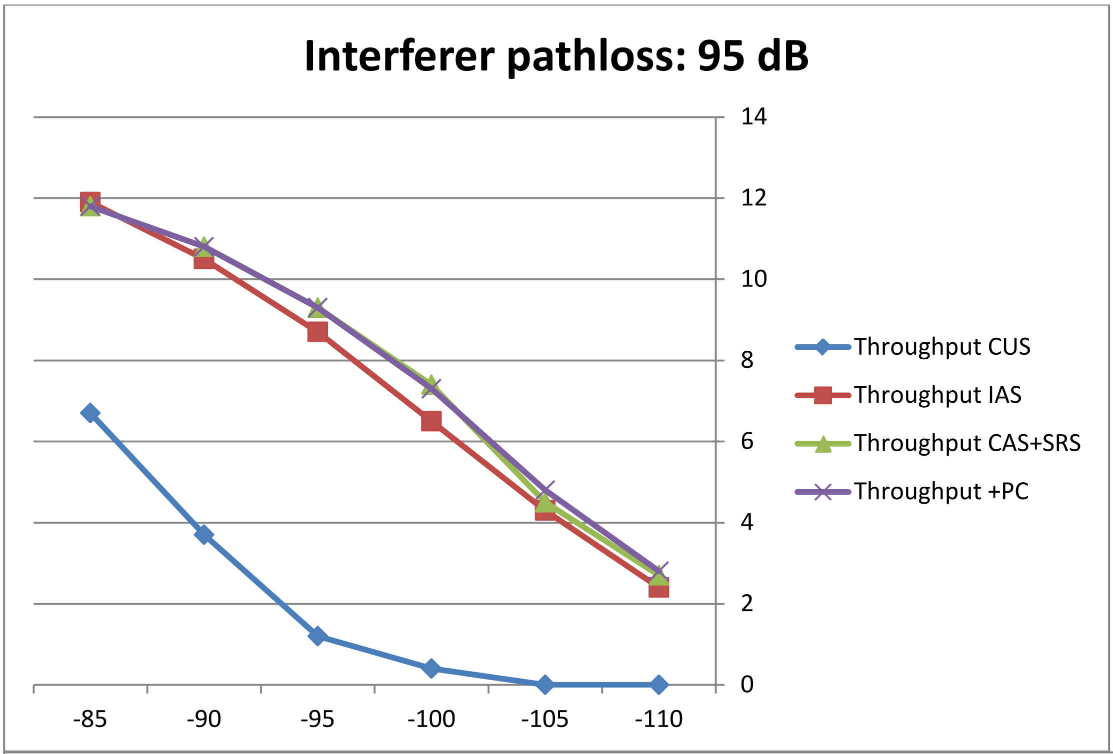

Interferer pathloss: 110 dB
14
12
10
8
6
4
2
0
-85
-90
-95
-100
-105
-110
Throughput CUS
Throughput IAS
Throughput CAS+SRS
Throughput +PC



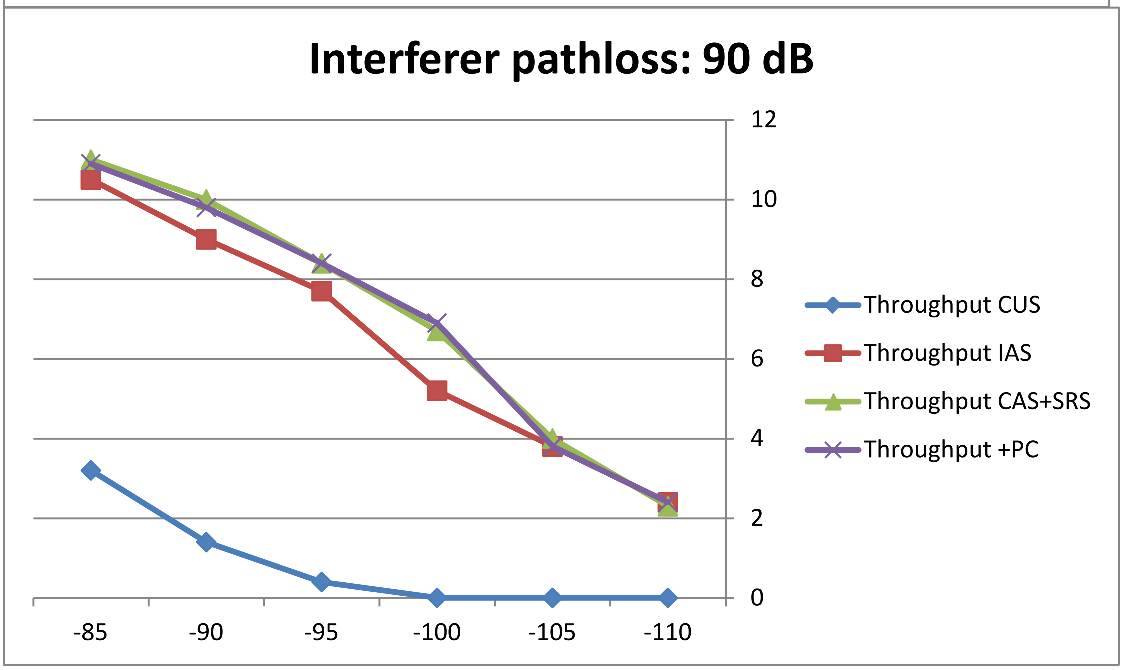
Interferer pathloss: 105 dB
14
12
10
8
6
4
2
0
-85
-90
-95
-100
-105
-110
Throughput CUS
Throughput IAS
Throughput CAS+SRS
Throughput +PC



Interferer pathloss: 100 dB
14
12
10
8
6
4
2
0
-85
-90
-95
-100
-105
-110
Throughput CUS
Throughput IAS
Throughput CAS+SRS
Throughput +PC



Interferer pathloss: 95 dB
14
12
10
8
6
4
2
0
-85
-90
-95
-100
-105
-110
Throughput CUS
Throughput IAS
Throughput CAS+SRS
Throughput +PC



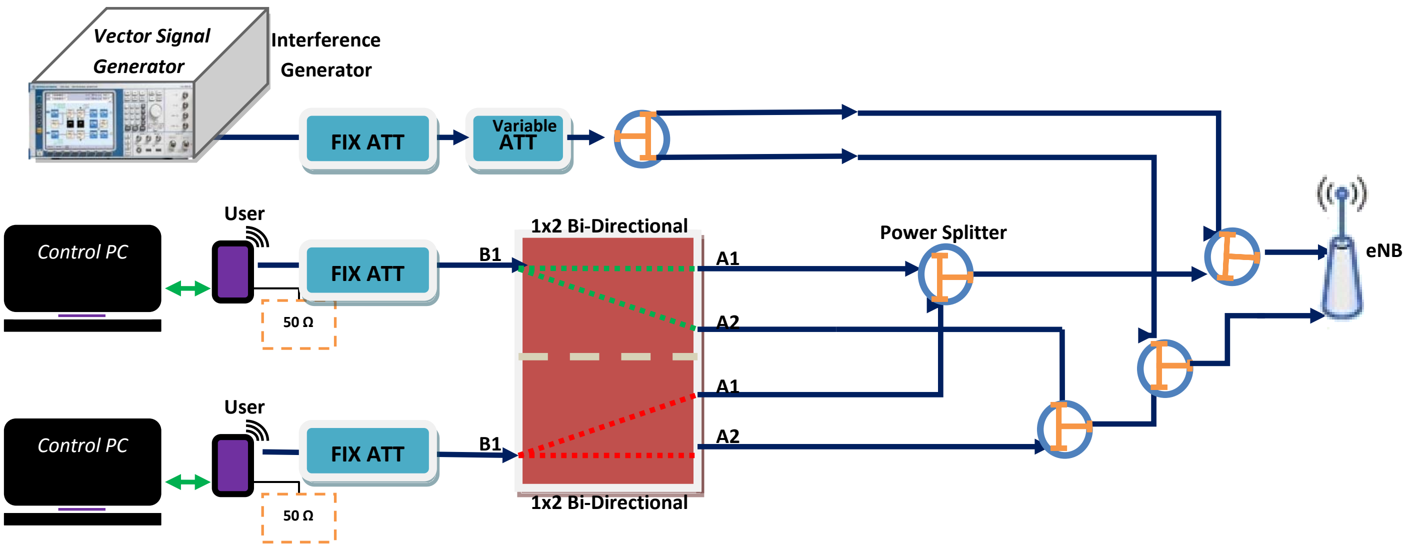
Interferer pathloss: 90 dB
12
10
8
6
4
2
0
-85
-90
-95
-100
-105
-110
Throughput CUS
Throughput IAS
Throughput CAS+SRS
Throughput +PC

Interference Aware Scheduling (IAS)

This section is dedicated to the Interference Aware Scheduling (IAS). System Parameters are listed as following:

- Upload channel
- 2600 MHz
- Channel Bandwidth = 15 MHz
- User Transmit Power = 21 dBm
- Signal Generator Transmit Power = 0 dBm
- Generated Interference Bandwidth = 4 MHz
- Sweep time of interference over the whole used Bandwidth = 100 ms
- Dedicated Each user PRB = 24 and 12

The scheme of the Test Bench is illustrated in below:



The First thing to Evaluate is the Model of the Path-loss which is existed in the test. This means the attenuations imposed by cables, connectors and etc. For this propose we place a simple user instead of the signal generator to evaluate the received RSRP, since we know the exact value of the transmitted power from eNB, the difference implies the fixed path-loss.

Transmit power of eNB is 30.6 dBm, since the received RSRP is -70 dBm with the variable attenuator equals to 39 dB in between, we can calculate the total path-loss equal to 100.6 dBm. Knowing the variable attenuator value (39 dBm) we can conclude that the fixed attenuation in path is equal 61.9 dBm

Table below shows the value of received RSRP with the fixed transmit power of eNB= 30 dBm (we deployed LTE-user instead of signal Generator to evaluate path-loss) with associated variable attenuators. The last column shows the received interference power in eNB when we substitute the interferer user with signal generator

eNB Tx Power dBb	User RSRP dBb	Total loss dB	Variable Attenuator dB	Sig. Gen. Tx power	Received Int. Power
30	-70	100	39	0	-100
30	-75	105	44	0	-105
30	-80	110	49	0	-110
30	-85	115	54	0	-115
30	-90	120	59	0	-120
30	-95	125	64	0	-125
30	-100	130	69	0	-130

with fixed transmit power of 0 dBm.

In the other side (users with throughput demand) the same evaluations have to be done. But this time we do not need to substitute users. Nevertheless, fading simulator can play the role of variable attenuator by its power adjustment capability in input and output.

Fix Path-loss for users branch was evaluated by previous measurement which the RSRP measured equal -85 dBm when the Tx power of eNB was 30 and fading simulator was set to 52 dBm of attenuation in downlink direction.

$$User_{RSRP} = eNB_{Tx_{power}} - Downlink\ F.S_{att} - Fix_{path-loss}$$

Table below shows the values of RSRP and associated variable attenuators in fading simulator. This value of attenuation, in fading simulator, with fix value of path-loss leads to receive of total mentioned power in eNB (last column). These values are actually implying the power of the useful signal in the receiver of eNB. Different scenarios form combination of different values of received signal and received interference were used to evaluate the throughout in IAS configuration of eNB.

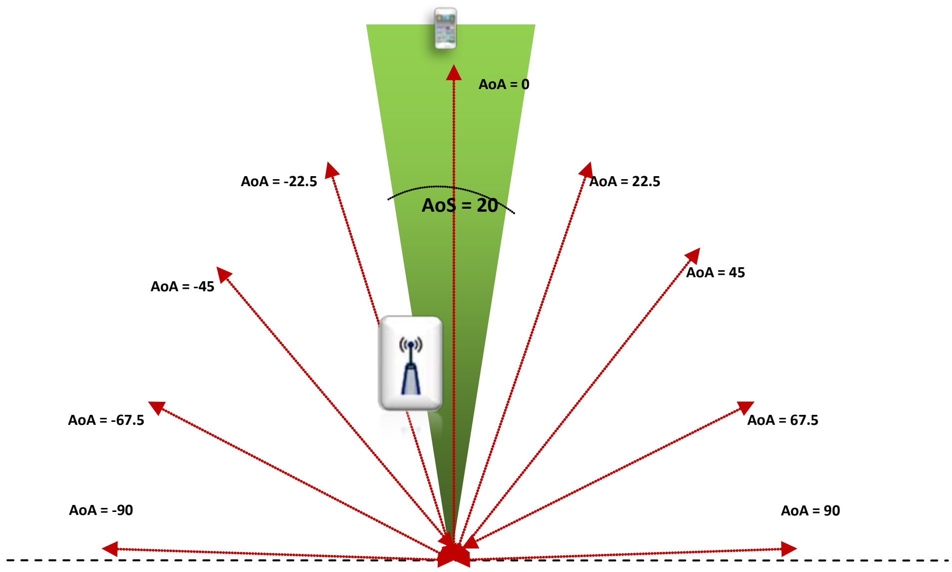
RSRP	User Tx power	Fad. ATT UL/DL	Fix path-loss	Total P.L. UL / DL	Rx power at eNB	Total Rx power
-85	21	57/52	67	124/119	-103	-100
-90	21	62/57	67	129/124	-108	-105
-95	21	67/62	67	134/129	-113	-110
-100	21	72/67	67	139/134	-118	-115
-105	21	77/72	67	144/139	-123	-120
-110	21	82/77	67	149/144	-128	-125

Interference Rejection Combining –IRC test

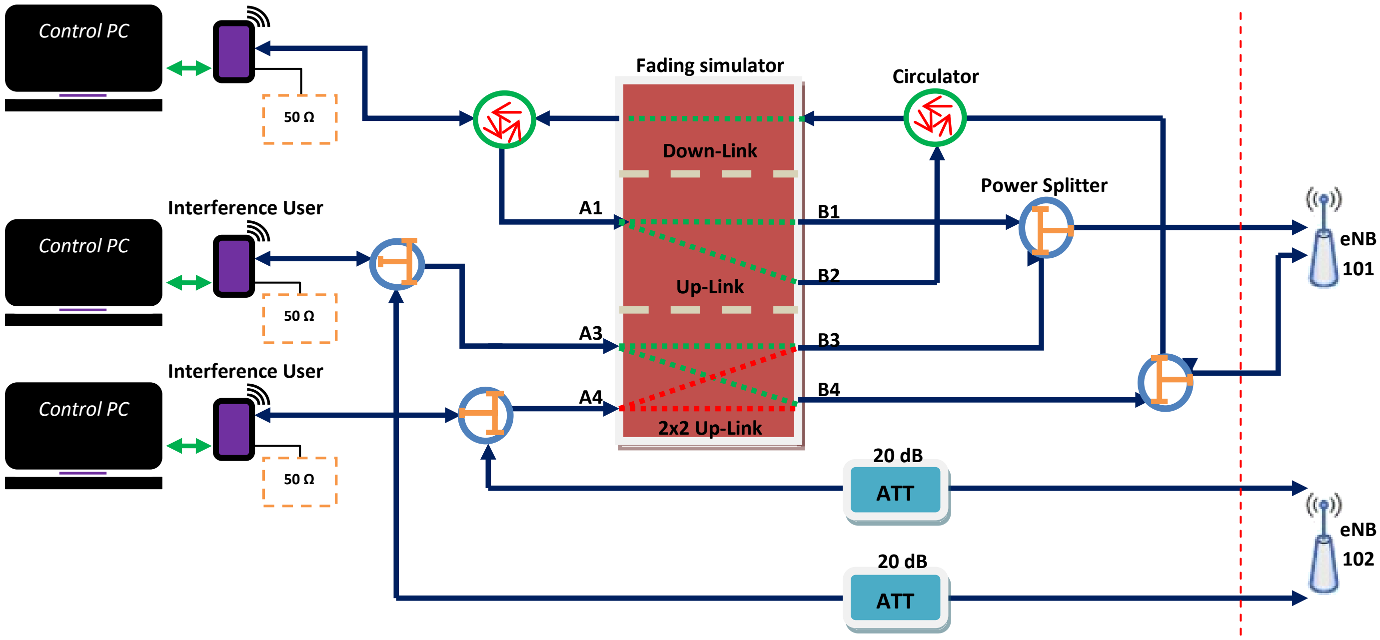
In this set of test we are going to evaluate the throughput of the uplink signal in different condition as described in following:

- Two different transmit power for interferer (-53 and -57dbm)
- Test with 1 and 2 interferers
- Useful signal power (output of fading simulator) = -52
- Nine different angle of arrival for the interfere (-90,-67.5,-45,-22.5,0,22.5,45,67.5,90 degree)
- AoS (Angle of spread)= 20 degree
- IRC-off (MRC- Maximum ratio combining) "maximum signal over noise" and IRC-on 'maximum signal over noise plus interference – all with CUS (channel unaware scheduler)
- EPA-3 movement profile
- 2600 MHz (2452.5 uplink, 2662.5 downlink)
- Mobile Tx power = 21dbm
- Synchronized and Desynchronized

In this picture the interferer position is illustrated in terms of angle of arrival:



Test bench structure is depicted as follows:



AoA - For each spatial factor profile (AoA) the correlation matrix is different. This particular matrix is already evaluated and given in the fading simulator in order to see the effect of different position in terms of angle of arrival.

AoS: is the HPBW (should be checked) of the eNB serving the useful signal. Note that useful signal (user) is always located in the line of sight of the eNB (receive highest power).

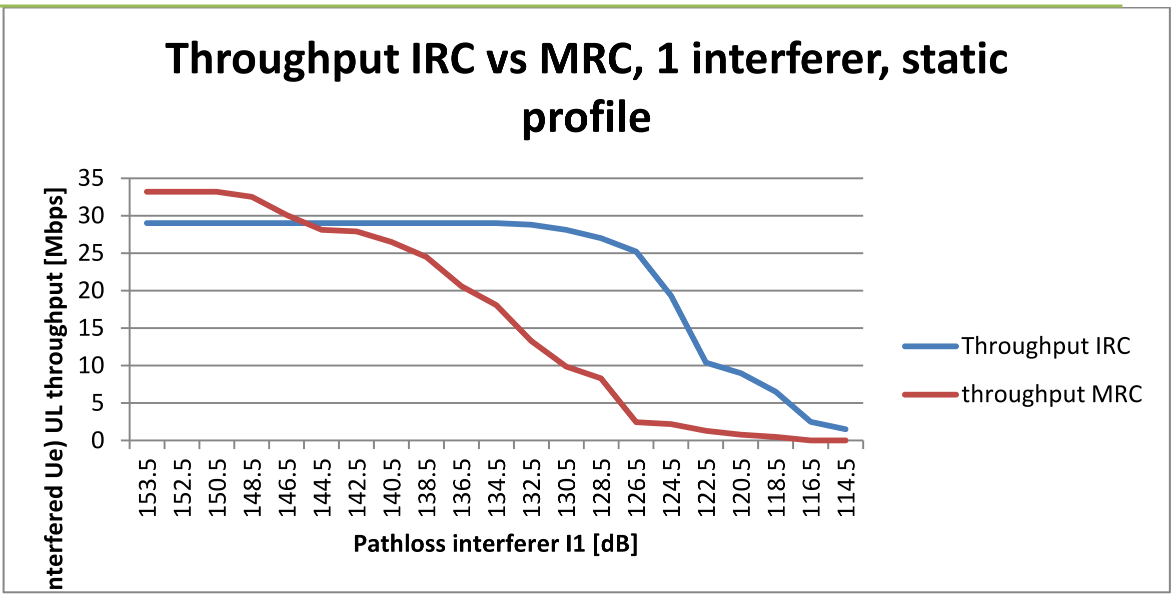
EPA-3: for this test the movement profile is always set to extended pedestrian with speed of 3 Km.

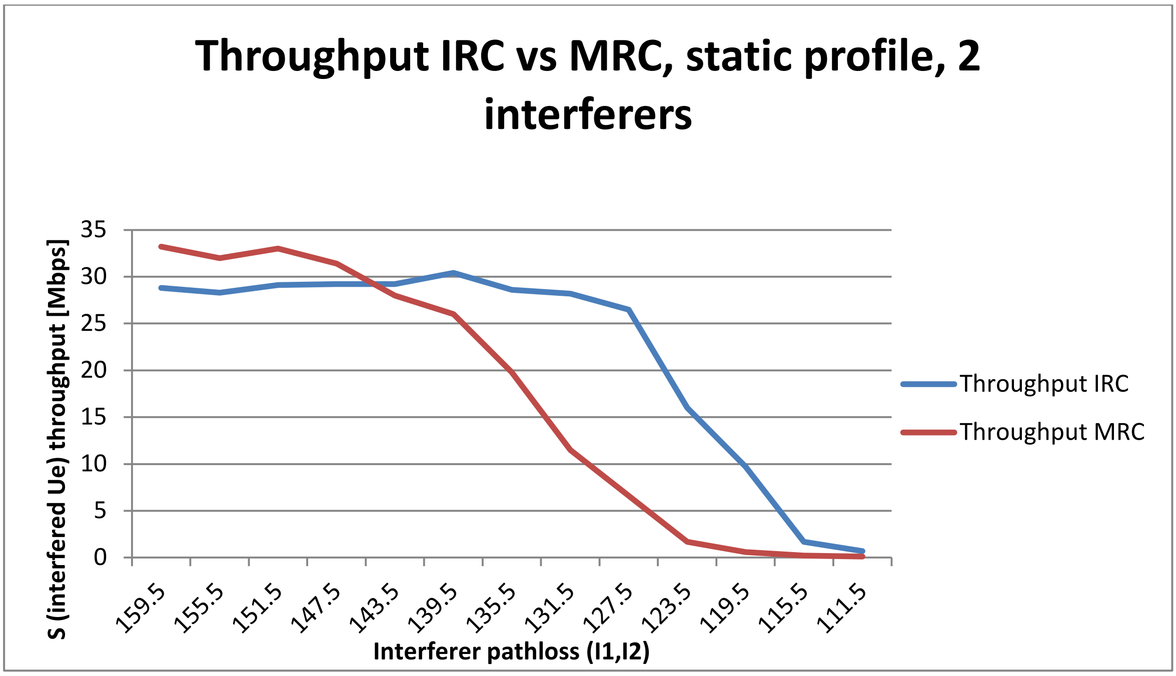
Synchronization: the synchronization in eNB is managed by GPS connection. Basically there are 2 kind of synchronization available for this propose

- Frequency synchronized
- Phase synchronized: this type of synchronization is more accurate than frequency sync.

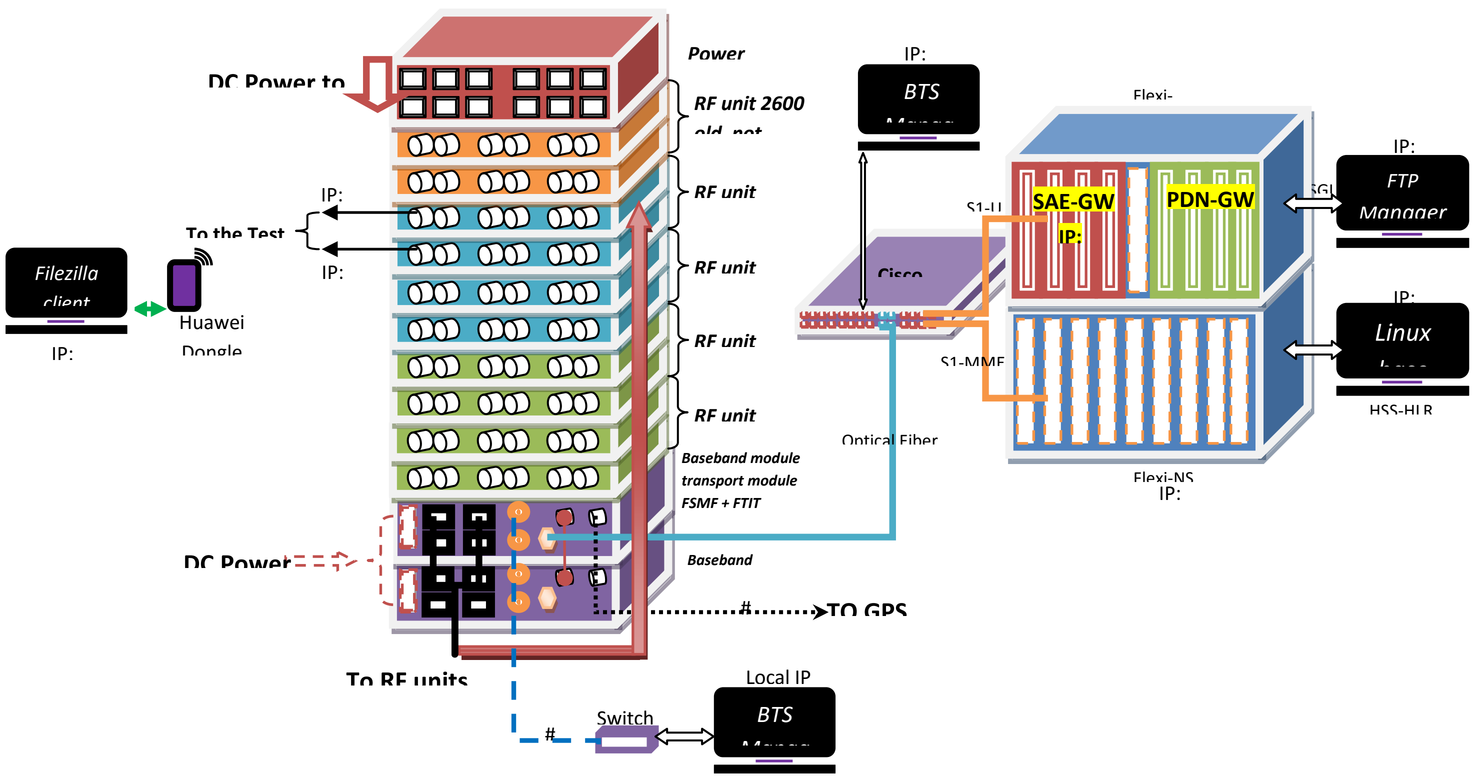
To perform the test in desynchronized situation we should use two, as independent as possible, backhaul which are supporting the useful and interferer users. To this aim we used different eNB for each one and each eNB is connected to its associated independent baseband module. Since we want to have not synchronized setting, different method of synchronization should be used for each baseband module (frequency and phase respectively)

Ue1 (S, useful signal)							Ue2 (I1, interferer 1)						Pathloss S	Pathloss I1
RSRP	TX power	Azimuth In	Azimuth Out set	Azimuth out meas	Throughput	UL PRB	RSRP	TX power	Azimuth In	Azimuth out set	Azimuth Out meas	Throughput		
-104	21	16	-54	-52	29	64	-100	21	2	-70	-75	22.1	133.5	153.5
-104	21	16	-54	-52	29	64	-100	21	2	-68	-74	22.1	133.5	152.5
-104	21	16	-54	-52	29	64	-100	21	2	-66	-72	22.1	133.5	150.5
-104	21	16	-54	-52	29	64	-100	21	2	-64	-70	22.1	133.5	148.5
-104	21	16	-54	-52	29	64	-100	21	2	-62	-68	22.1	133.5	146.5
-104	21	16	-54	-52	29	64	-100	21	2	-60	-66	22.1	133.5	144.5
-104	21	16	-54	-52	29	64	-100	21	2	-58	-64	22.1	133.5	142.5
-104	21	16	-54	-52	29	64	-100	21	2	-56	-62	22.1	133.5	140.5
-104	21	16	-54	-52	29	64	-100	21	2	-54	-60	22.1	133.5	138.5
-104	21	16	-54	-52	29	64	-100	21	2	-52	-58	22.1	133.5	136.5
-104	21	16	-54	-52	29	64	-100	21	2	-50	-56	22.1	133.5	134.5
-104	21	16	-54	-52	28.8	64	-100	21	2	-48	-54	22.1	133.5	132.5
-104	21	16	-54	-52	28.1	64	-100	21	2	-46	-52	22.1	133.5	130.5
-104	21	16	-54	-52	27	64	-100	21	2	-44	-50	22.1	133.5	128.5
-104	21	16	-54	-52	25.2	64	-100	21	2	-42	-48	22.1	133.5	126.5
-104	21	16	-54	-52	19.3	64	-100	21	2	-40	-46	22.1	133.5	124.5
-104	22	16	-54	-52	10.4	64	-100	21	2	-38	-44	22.1	134.5	122.5
-104	22	16	-54	-52	9	64	-100	21	2	-36	-42	22.1	134.5	120.5
-104	22	16	-54	-52	6.5	64	-100	21	2	-34	-40	22.1	134.5	118.5
-104	22	16	-54	-52	2.5	60/64	-100	21	2	-32	-38	22.1	134.5	116.5
-104	22	16	-54	-52	1.5	30/36	-100	21	2	-30	-36	22.1	134.5	114.5





Overall Network Structure for Test of IRC



Acknowledgment

This report would not have been possible without the guidance, help and supervision of Eng. Loris Bollea who his invaluable knowledge and experiences helps me in the preparation and completion of this report.

I want to appreciate my tutor in Telecom Italia, Prof Fabrizio Gatti, and Dr. Umberto Ferrero for giving me the opportunity to visit Telecom Lab and my adviser professor, Prof. Claudio Casetti. I am also deeply indebted to all the other tutors and researchers and employee of the Telecom Italia Lab for their direct and indirect help to me.

Table of Contents

Chapter 1: Test Bench Setting and Structure Overview for CoMP Test

Test Bench and Instruments Overview

Following instruments are used to perform the test on Coordinated MultiPoint for uplink in LTE-A infrastructure.

1. Complete LTE-A cellular network set:

- eNB (2 systems): also known as Evolved Node B, is the hardware that is connected to the cellular network communicating directly with users. Associated bandwidth and central frequency are 10 MHz and 2.6 GHz respectively.

- GW/MME: Gateway/Mobility Management Entity is an access gateway platform which is in charge of connection control, load balance, scheduling and mobility management.

- FTP Server: according to test data traffic transmission between client and server, there is a server computer connected to the GW/MME to receive a data from UE trough the LTE-A network.

- Connections: Since the experiments were done in laboratory, we used cable connection instead of free space (air-channel)

2. User receiver side:

- LTE-A Dongle (1 piece): Simple LTE-A Dongle is used for the tests.
- Computer (1 system)

3. Attenuators (4 pieces): In order to emulate the path-loss we used variable attenuators. Therefore, more attenuation is associated to more ranges. Four attenuators are needed to test CoMP with "MIMO 2x2" functionality.

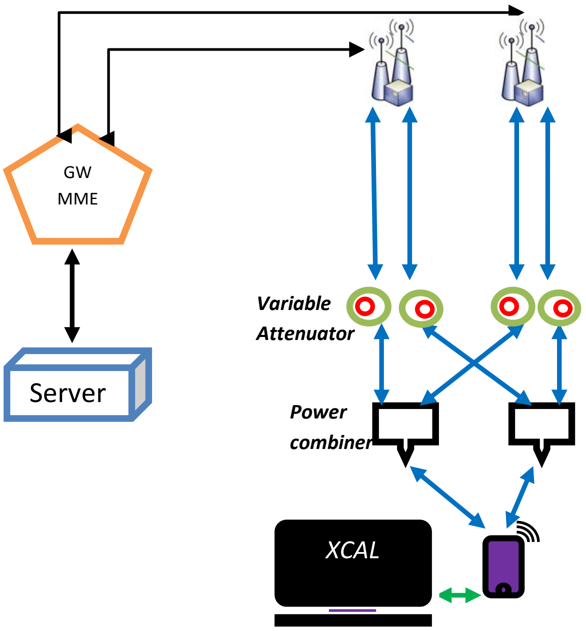
4. Combiners - Non directional splitters (2 pieces): Since LTE-A uses MIMO, and in this case we test the functionality with MIMO 2x2, 2 power combiners (non directional power splitter), are needed to merge four received signals into two inputs for LTE-A dongle.

In order to test CoMP in our desired infrastructure, first we need a complete LTE-A network set consisting of:

- Two eNodeBs with MIMO and CoMP capability
- GW/MME
- FTP Server computer to control data flow
- Four variable attenuators
- Two power combiner

This test process evaluates the throughput in uplink connection. Likewise, Personal computer, which is connected to the LTE-A dongle in UE's side, is also connected to the server computer through the same network connection. Data file, traffic, which is stored in pc, is transferred to the FTP server through LTE network. Software called "XCAL", installed on user side pc, is responsible for:

- Uploading data file to the dongle via USB connection
- Measurement of Reference Signal Received Power (RSRP)
- Monitoring the control massages in network and between dongle (user) and eNB
- Monitoring the Modulation and Coding Scheme (MCS) and etc.



Uploaded data, using CoMP technique, are received by two eNodeBs after passing through a path, schematic is shown in picture above. As soon as received data are de-modulated and de-coded in eNB, they are transmitted to the GW/MME and respectively from GW/MME to server computer. Server computer informs the P.C of the correctness of the received data via installed software designed for this proposes. Evaluation of throughput can be obtained from the mentioned software (Netpersec).

Test Procedure for Uplink CoMP

Before and during the test some parameters have to be adjusted which are listed as follows:

Software Settings:

- Putty: This software is used to remote control the server computer connected to the GW/MME. since we are interested in connection remotely to the FTP server, it is just enough to insert the destination, FTP server IP, in order to access to it. With the following commands we can upload the traffic to the FTP server

```
c:\> ftp "FTP server IP "
c:\> Put "filename" // or Get "filename"
```

- XCAL: This software is used to monitor the LTE networks massages, RSRP, SINR, and etc. There are 2 main windows, "signalling massages" and "user defined table". In signalling massage window we can observe commands and signals according to their time, channel, ID and massage. Its main usage, in our case, is to be aware of CoMP status or Handover event according to transmitted massages. In "user defined table" there is a possibility to add and observe connection statuses like: power info, serving cell info, best neighbour cell info, channel quality info, UL and DL info and radio link monitoring information.
- Netpersec: This software is used to visualize the uplink and downlink throughput in the network.

Variable Attenuators: In the case of real environment users are moving in the cell, covered by each eNB. Moving toward or against the serving cell, leads to incrementing or decrementing Reference Signal Received Power (RSRP) respectively. This behaviour is easily simulated with four variable attenuators, coupled two by two, in laboratory. Values of each coupled attenuators have to be equal because they both always simulate a same channel between user and associated eNB. Considering fixed Path loss for both channels following values of attenuation have to be adjusted to obtain desired RSRP.

RSRP	-90	-93	-96	-96	-99	-102	-105	-108	-111	-114	-117	-120
SERVING CELL ATT	16	19	22	25	28	31	34	37	40	43	46	49
NEIGHBOUR CELL ATT	28	31	34	37	40	43	46	49	52	55	58	28

During the test we respectively change the attenuation values of the neighbour cell by decreasing manner for a fixed power (attenuation) for serving cell and observe the results for each value of RSRP.

Conditions: There are two different conditions in terms of CoMP and handover which should be adjusted in the eNB configurations

- *Handover Condition:* Handover should happen when RSRP of the neighbour cell is 3 dB more than RSRP of the serving cell. This gap actually prevents the handover procedure from ping-pong effect. Handover condition can be seen as follows:

$$RSRP_{neighbour} > RSRP_{serving} + 3_{dB}$$

- *CoMP condition*: Coordinated multipoint should happen when the received power of the neighbour cell is within the certain range of the serving cell. This condition implies the cell edge condition where, receiver RSRPs from two cells, serving and neighbour, are in the same order. This region is exactly the region of interest where CoMP has the highest efficiency. The CoMP condition can be seen as follows:

$$RSRP_{neighbour} > RSRP_{serving} - 8_{dB}$$

Therefore, coordinated multipoint can happen in illustrated region

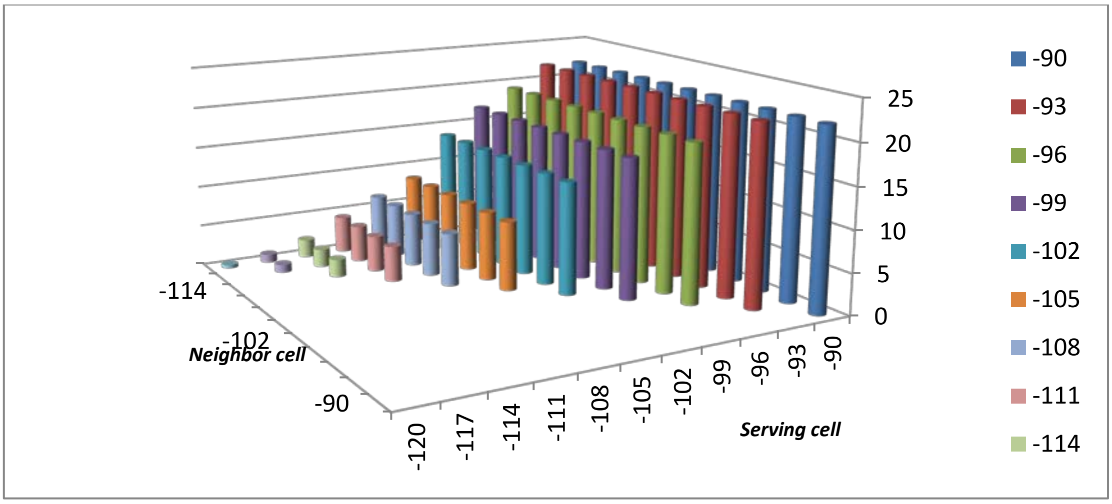
$$RSRP_{serving} + 3_{dB} > \ CoMP\ Happens > RSRP_{serving} - 8_{db}$$

Results

Measurements are obtained in two different major cases. In the first one, results show the throughput in standard handover (without CoMP), while in the second one, a set of measurement throughput values are obtained with the CoMP capability. In the following table the obtained throughput are shown without the CoMP capability.

No CoMp	Neighbor, PCI= 3													
	ATT		28	31	34	37	40	43	46	49	52	55	58	REF
		RSRP	-90	-93	-96	-99	-102	-105	-108	-111	-114	-117	-120	-200
Serving Cell, PCI = 1	16	-90	22	22	22	22	22	22	22	22	22	22	22	22
	19	-93		22	22	22	22	22	22	22	22	22	22	22
	22	-96			19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2
	25	-99				17	17	17	17	17	17	17	17	17
	28	-102					13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7
	31	-105						8.4	8.4	8.4	8.4	8.4	8.4	8.4
	34	-108							6.5	6.5	6.5	6.5	6.5	6.5
	37	-111								4.4	4.4	4.4	4.4	4.4
	40	-114									2.2	2.2	2.2	2.2
	43	-117										1	1	1
	46	-120											0.4	0.4

In the table above it can be seen that changing the neighbour cell RSRP does not have any effect on measured throughput. Graphical bar chart of results is illustrated below:

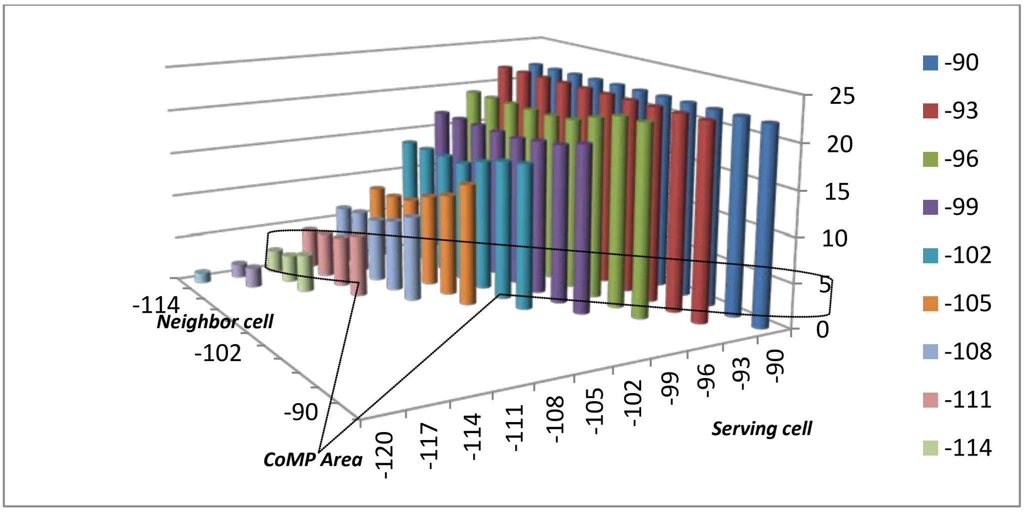


In spite of the above case, the measurement with the CoMP capability shows the increment in throughput where the neighbour RSRP is comparable with the serving one with the following condition.

$$RSRP_{serving} + 3_{dB} > \ CoMP\ Happens\ > RSRP_{serving} - 8_{db}$$

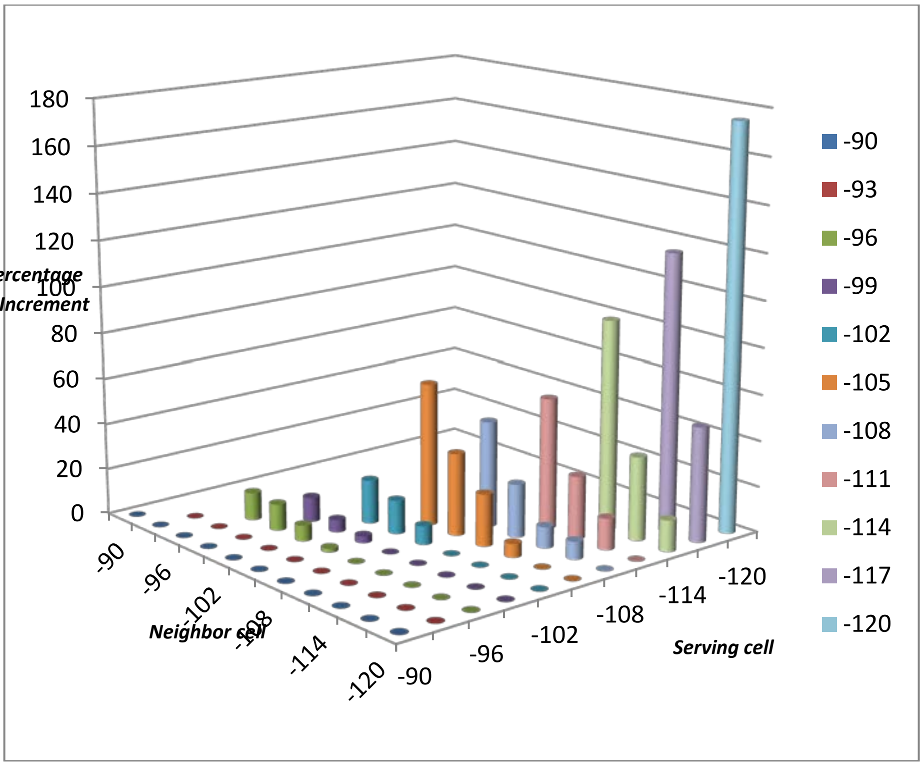
CoMp	Neighbor, PCI= 3													
	ATT		28	31	34	37	40	43	46	49	52	55	58	REF
		RSRP	-90	-93	-96	-99	-102	-105	-108	-111	-114	-117	-120	-200
Serving Cell, PCI = 1	16	-90	22	22	22	22	22	22	22	22	22	22	22	22
	19	-93		22	22	22	22	22	22	22	22	22	22	22
	22	-96			21.5	21.4	20.5	19.5	19.2	19.2	19.2	19.2	19.2	19.2
	25	-99				18.8	17.9	17.5	17	17	17	17	17	17
	28	-102					16.3	15.7	14.8	13.7	13.7	13.7	13.7	13.7
	31	-105						13.6	11.4	10.3	8.9	8.4	8.4	8.4
	34	-108							9.5	8	7.1	7	6.5	6.5
	37	-111								6.9	5.6	5	4.4	4.4
	40	-114									4.2	3	2.5	2.2
	43	-117										2.2	1.5	1
	46	-120											1.1	0.4

It can be seen that the upper triangle of the chart are filled, this phenomena could be discussed as a result of handover. As it mentioned before handover happens when neighbour cell received power is 3 dB more that then received power of the serving cell, and that is exactly where serving and neighbour cell are swapped. Since our structure according to therefore attenuators, power splitters and eNB is symmetrical, same throughput measurements are valid for swapped case.



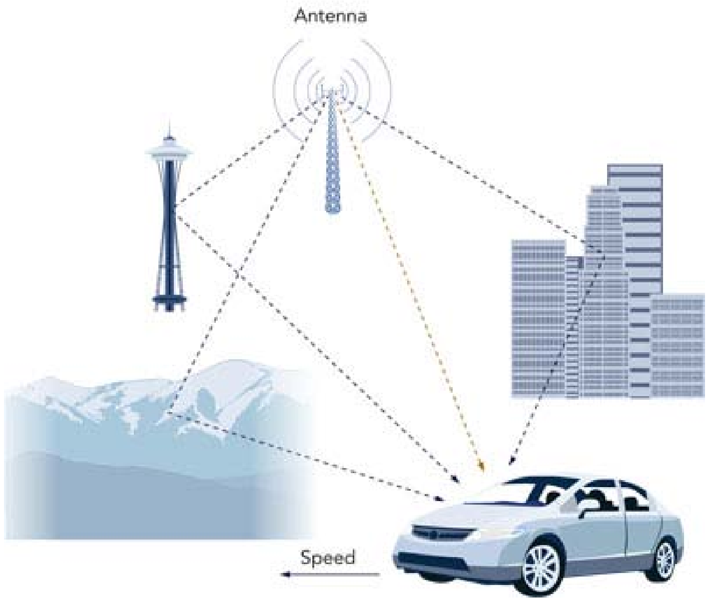
It can be seen from the bar chart above that the maximum throughput, for fixed serving cell power, is happened with that highest possible power (but not 3 dB more than serving) of neighbour cell.

Bar chart in the following shows the increment percentage in upload throughput in different scenarios, depending on the RSRPs. The results clearly show that CoMP technique has the best performance in regions where RSRP of the serving cell has the lower value. In other words, Coordinated Multipoint mostly enhances the cellular network quality in cell edges.



Chapter 2: Fading and Channel Simulation and Associated Test Bench

In wireless communications, fading is deviation of the attenuation affecting a signal over certain propagation media. The fading may vary with time, geographical position or radio frequency, and is often modeled as a random process. In wireless systems, fading may either be due to multipath propagation, referred to as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading. Fading channel models are often used to model the effects of electromagnetic transmission of information over the air in cellular networks and broadcast communication[1].



According to tests which are done in lab, the same channel condition similar to the real environment, in terms of fading and multipath, should be efficiently emulate between a base-station transmitter and a mobile receiver. As in real environment, since a signal transmitted over the air, it is subject to fading. The signal can be absorbed or reflected by obstacles such as buildings, mountains, and trees and the resulting fading can influence its amplitude and phase significantly. The same condition should be applied to the raw signal, transmitted through wire in lab, in order to reconstruct the desired scenario. Depending on the selected scenario such as urban, pedestrian or etc, proper enough paths with associated delays and attenuations should be considered. Moreover with a moving receiver, additional challenges occur such as maxima and minima of signal strength and Doppler shift. Due to the test of wireless equipment in laboratory to match with real test, in free space and real environment, proper fading emulator is needed to obtain valid results

[1] www.wikipedia.org

Fading and Channel Emulator

LTE-A (4G) promises throughput speeds of 1Gbps in downlink and up to 500 Mbps for delivery in uplink connection, data and video services. To deliver such throughput speeds, LTE solution employ orthogonal frequency-division multiplexing (OFDM) and advanced antenna techniques such as Multiple- Input, Multiple-Output (MIMO). MIMO performance depends on the radio channels in which it operates, and accurate and repeatable laboratory characterization of RF environmental effects such as multipath and fading on the conformance, performance and interoperability of OFDM and MIMO-based systems can only be achieved through the use of channel emulation. According to the mentioned description of LTE infrastructure there are some test cases which have to be followed in the laboratory[2] as follows:

- Test MIMO algorithms and debug errors
- Evaluate and optimize the performance of wireless devices
- Streamline QA processes for new devices
- Perform competitive performance benchmarks
- Verify that devices meet Radio Conformance Test metrics
- Validate interoperability for MIMO/SISO devices
- Run handover and interference tests
- Test handoff between radio technologies such as W-CDMA and LTE

ACE™ MX – MIMO Channel Emulator

The ACE MX is a channel emulator, purpose-built to support MIMO transmissions and architected to meet the demanding RF needs of OFDM based systems. The ACE MX product line combines industry-leading channel emulation capabilities in a comprehensive design to deliver a range of configurations for MIMO and/or SISO system testing, with uni- and bi-directional configurations[3]. It performs real-time lab emulation of a multipath fading environment. This device, combined with a graphical user interface, makes set up, configuration and test execution quick and easy.

[2] www.azimuthsystems.com
[3] www.azimuthsystems.com

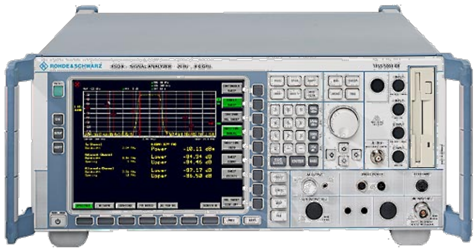
Vector Signal Generator

Vector Signal Generator ¸SMU200A

The R&S®SMU200A vector signal generator has been designed to meet all requirements encountered in the research and development as well as production of modern communications systems. This system combines two independent signal generators and it also offers unrivaled RF and baseband characteristics. Two generators have the ability to generate complex signals in real-time and with an arbitrary waveform. The signals generated in the different basebands can be also added to the main path. Featuring a dual-path concept and an optional integrated multichannel fading simulator, this device is ideal for tests on MIMO receivers as 2x2 MIMO systems can be tested using a single instrument. For larger systems up to 2x4 or 4x2 MIMO, two instruments can be combined. Some capabilities, related to our test, of the mentioned device are listed as follows[4]:

- Generation of EUTRA\LTE in the baseband configuration
- Two different independent paths suitable for MIMO simulation (2x2 MIMO)
- Channel Fading Capability
- Capability of adding additive white Gaussian Noise to the signal in each path
- I/Q mode configuration

Vector Signal Generator



Signal Analyzer

Signal Analyzer

Signal Analyzer ¸FSQ 26

A signal analyzer employs digital techniques to extract useful information that is carried by an electrical signal. In common usage the term is related to both spectrum analyzers and vector signal analyzers. While spectrum analyzers measure the amplitude or magnitude of signals, a signal analyzer with appropriate software or programming can measure any aspect of the signal such as modulation. Today's high-frequency signal analyzers achieve good performance by optimizing both the analog front end and the digital back end.

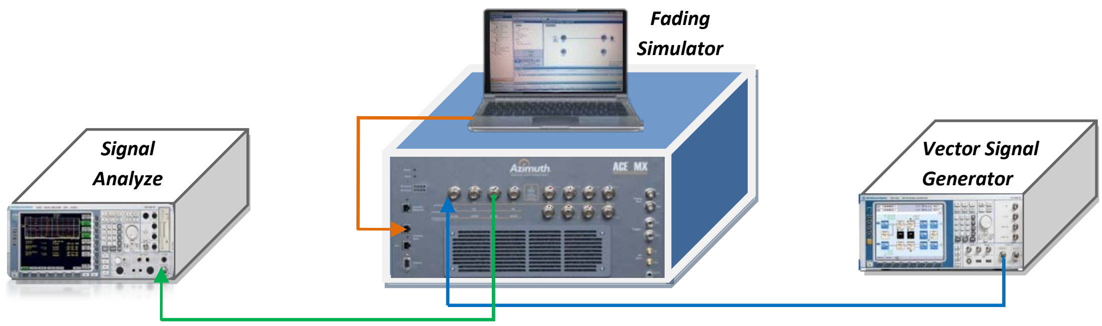
A signal analyzer can be viewed as a measurement platform, with operations such as spectrum analysis (including phase noise, power, and distortion) and vector signal analysis (including demodulation or modulation quality analysis) performed as measurement applications[5].

[4] www.rohde-schwarz.com
[5] www.rohde-schwarz.com

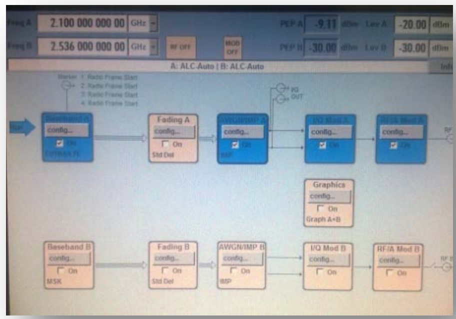
Test Bench Overview and Settings

Test bench can be observed as follows. There are totally 3 connections deployed in this test to emulate real environment.

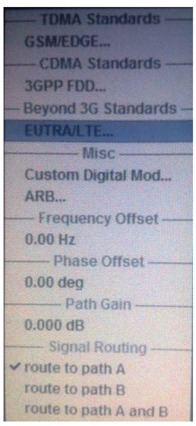
- Vector Signal Generator to Fading Simulator
- Fading simulator to Signal Analyzer
- Computer to Fading Simulator (control and configuration)



In order to have a proper test some settings have to be adjusted in these 3 systems that are described.



Vector Signal Generator: As it can be observed in the picture, this devise has dual independent signal generators. Since we are not testing MIMO in this experiment, the adjustments are just applied to one of the paths.



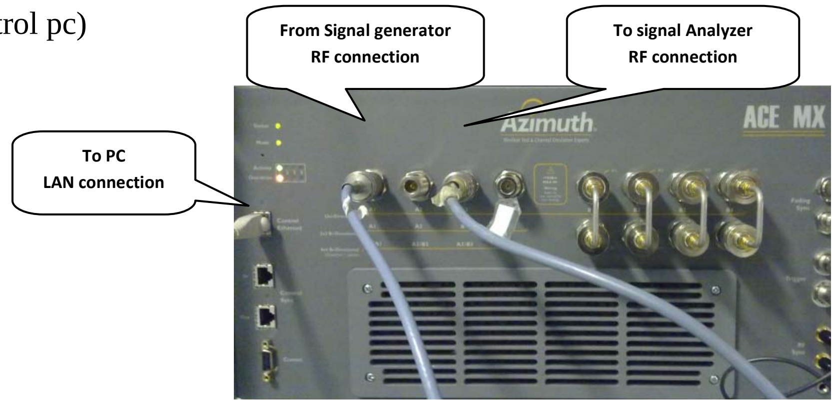
1. Base band adjustment: Since we aimed to test and observe fading on LTE signal, EUTRA/LTE was selected for baseband option.

2. Fading adjustment: we prefer to simulate fading with fading simulator but not this option; therefore we did not apply any fading and multi-path effect in this step.

3. AWGN: No setting just like fading setting.

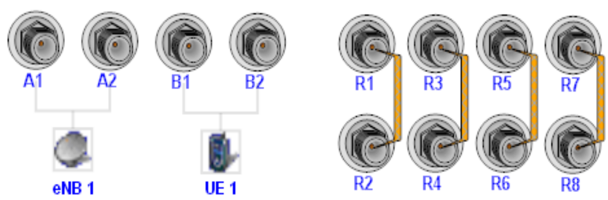
Signal Analyzer: As far as this test was concerned, basic adjustments, frequency and etc., were enough in this case.

Fading Simulator: It can be observed in the picture below, there are only 3 connections available from/to outside (from vector signal generator, to signal analyzer and to control pc)



Fading Simulator settings:

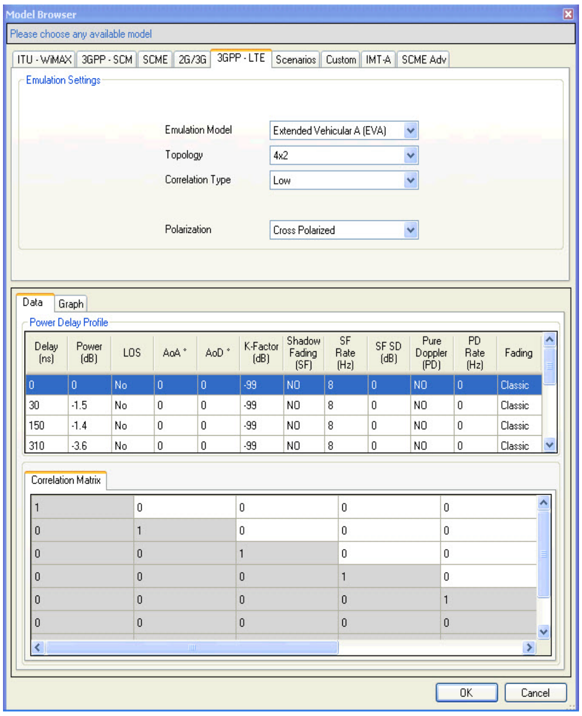
1. Configure the system: according to the test with more than one simulator the controller should be aware of the number and synchronization of each simulator connected to it.
2. External devices:
   - Base station devices: In this case number of eNBs.
   - Mobile devices: In this case number of users.
3. Connection manager: Associate each base station on mobile device to its own connected port. The picture illustrates the part of connections of fading

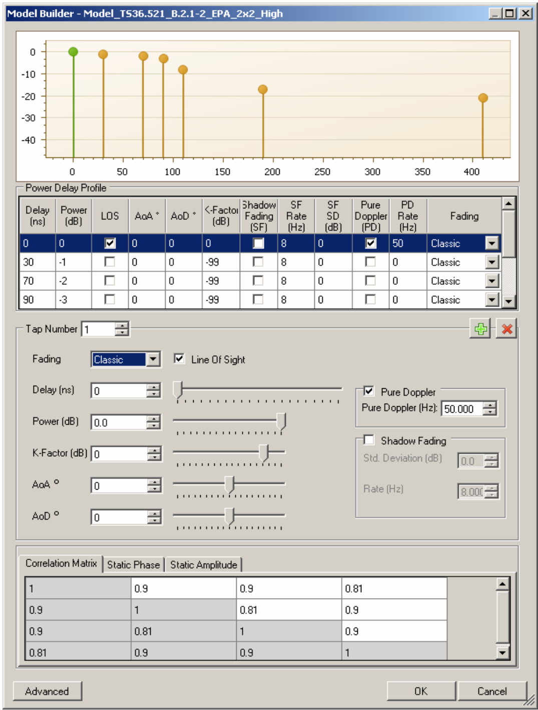


simulator in front panel.

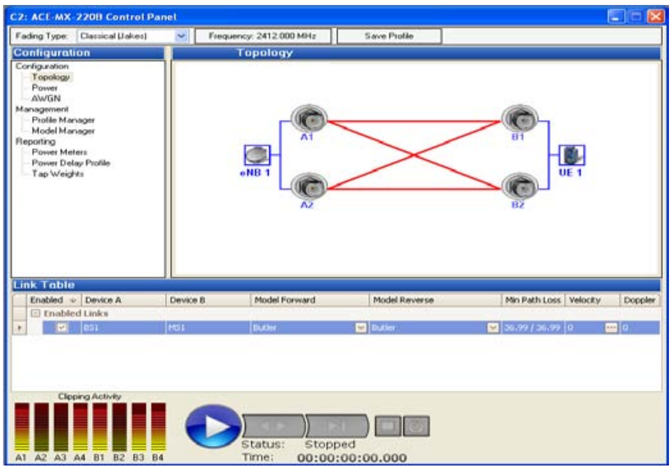
4. Fading parameter and AWGN settings:
   - AWGN: Additive White Gaussian Noise (AWGN) introduces spectrally flat noise over the faded signal and is used in the analysis, modeling and performance prediction of communication systems. AWGN can be added to each RF output to allow the user to accurately set a signal-to-noise ratio of the output signal transmitted to the device under test.
   - Fading: Enhanced channel modeling capabilities of the ACE MX enable the configuration of diverse and complex channel conditions. The Emulator

supports a large number of taps, long path delays and very flexible antenna correlation capabilities. Channel models can be defined static or dynamic in terms of movement over the time. This device has dynamic model capabilities that allow fading and multipath conditions to be varied over time. This procedure affects dynamic Doppler velocity to recreate authentic lifelike motion. Standard models can be selected from the model manager (left picture) and specific custom models can be created and saved using the custom model manager (right picture)





The software is capable to define various taps (Fading profile) for each connection (between base station and user). For each single tap there is a possibility of changing the model for fading and values of delay, power, k-factor, and etc. According to each tap, there is a correlation matrix which should be filled with proper correlation values for MIMO application.



Simple model of 2x2 MIMO connections between user and eNB

Chapter 3: Simulation

The simulation phase consists of some functions as follow:

Main Program:

- Input parameters
- Input measured data
- Planning the network layer
- Movement profile
    - Speed distribution
    - Movement or walking algorithm
- Path-loss calculation upon to the associated model
- Applying the CoMP function
- Display the results

Mentioned functions are described later.

Input Parameters

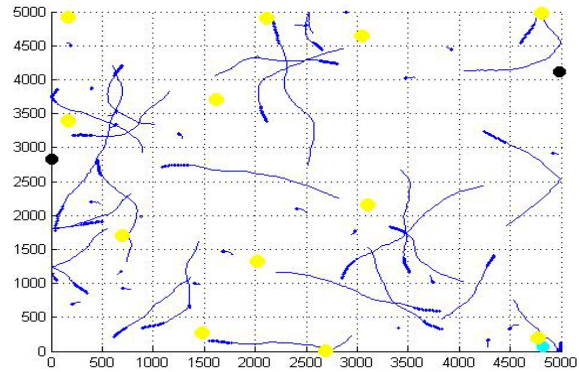
- Covered area dimensions
- Number of Pico and Micro cells
- Number of users
- Simulation time (number of snapshots)
- Simulation time step
- User's speed distribution: two Gaussian distribution with associated mean and variance
- Users transmit power
- Frequency Band
- Walking smoothness parameter
- CoMP active margin (Ref. P.5)
- Handover offset (Ref. P.5)
- Number of cells contributing in CoMP process
- Model of path-loss

Input Measured Data

Since we measure the through for CoMP condition in Telecom Lab, the obtained results are based on mentioned data. Notice that this set of measurements are just valid for one neighbor cell with the CoMP and handover margin of 8 and 3 dB respectively.

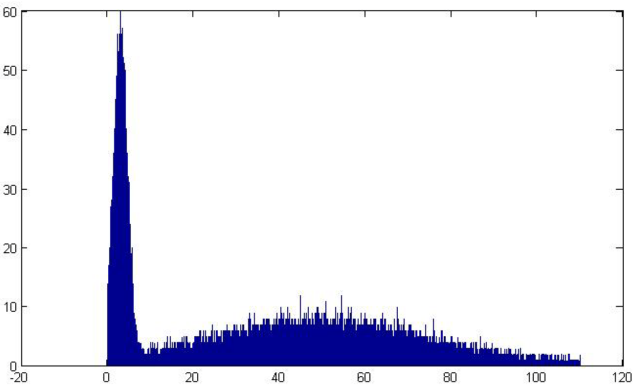
Network Layer

After setting the area dimensions and number of eNBs and users, the program automatically and randomly distribute located Micros, Picos, and users in the way that there is a minimum distance between them. Therefore, no pair of micro cells of Pico cells is located close to each other (there is a minimum distance between them). In the picture below colored circle shapes are shown as eNBs and blue lines are walk roots.



User's speed distribution

Since I used my own model of walk, I decide to use a Gaussian distribution for speed. There are two models for velocity in my program, first one for low-velocity users and another one for higher-speed users. Associated mean value and variance of the Gaussian distribution can be set as input parameter in the beginning of the program. In this case I used Gaussian distributions with means of 3 and 50 Km per hour and variance of 1.5 and 20 Km per hour respectively.



Walking smoothness parameter

Since I used a random walk model, for each orientations of movement is limited by this parameter. Therefore users walk model smoothness can be adjusted with this parameter. In other words this number limits the orientation of the movement in term of angle.

Model of path-loss

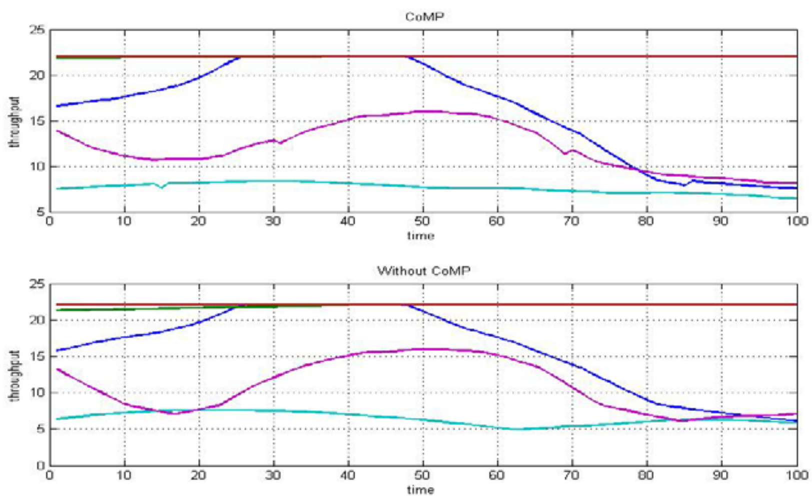
I used two simple models for path-loss. First one is a formula for both micro and Pico cells, the other model uses different path-losses for Micro and Pico cells. In future versions I will also try Friis or Hata model for path-loss. This parameter can be also adjusted in the program.

Matlab Results

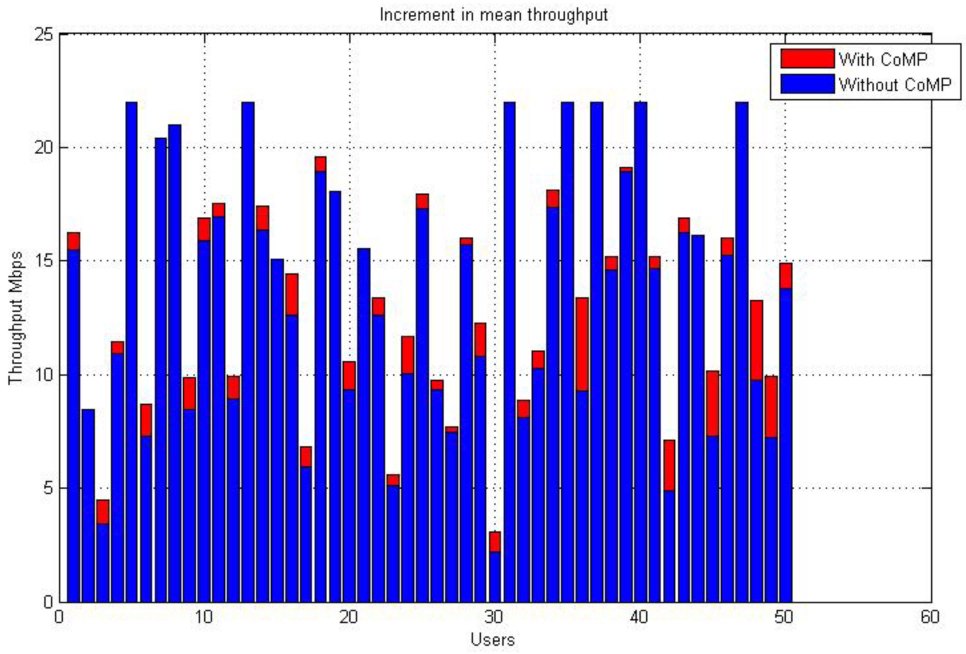
For input parameters of

- Covered area dimensions (5 Km * 5 Km)
- Number of Pico and Micro cells (10 Pico and 5 Micro)
- Number of users = 50
- Simulation time (number of snapshots) = 100 snapshot
- Simulation time step = 1 sec
- User's speed distribution: two Gaussian distribution with associated mean and variance
- Users transmit power = 20 dBm
- Frequency Band = 2600 MHz
- Walking smoothness parameter
- CoMP active margin (Ref. P.5) = 8 dB
- Handover offset (Ref. P.5) = 3dB
- Number of cells contributing in CoMP process = 1 active CoMP

The obtained results are depicted in the graphs below. Variations in throughput of five users during simulation time can be seen in two different situations, First with the CoMP functionality and other one without the CoMP.



The following graph shows the means throughput of the users with and without the CoMP during the simulation time.



Simulation Enhancement phase

Since this simulation was done with very limited and constrained situation and condition, more realistic values and conditions are needed and should be applied in order to obtain valid results. Some of the mentioned condition and needed values are listed in below:

- Number of eNBs (Micro and Femto cells) and users
- Real Path-loss calculation algorithm
- Possible fading techniques
- Movement profile and concentration of the users
- Users demand profiles and connection in terms of throughput
- Number of Active eNBs having contribution in CoMP or Number of possible active neighbor cells
- Measurement results of throughput, as reference, with desired number of active neighbor cells
- Relevant scheduling algorithm techniques

Prior Art

LTE-Advanced meets the challenge raised by powerful, mobile devices and bandwidth-hungry applications by investing in solutions such as carrier aggregation, higher order MIMO, relay nodes and Coordinated Multipoint (CoMP) transmission/reception. The latter, in particular, is envisioned to be one of the most important techniques in LTE-Advanced to improve the throughput and functionality of cell borders [1.] CoMP allows users to have multiple data transmission and reception from/toward multiple cooperating eNodeBs (eNBs), increasing the utilization factor of the network. Resource allocation in the uplink is especially beneficial because more sophisticated algorithms can leverage the availability of additional connection points where the signal from the User Equipment (UE) is processed, ultimately providing UEs with increased throughput. Additionally, a significant part of the interference caused by neighboring cells can be seen as a useful received signal thanks to CoMP, provided those cells are part of the Coordinated Reception Point (CRP) set. This is especially important in critical regions, in terms of interference, like cell edges. Finally, in the case of joint multi-cell scheduling, CoMP introduces a reduction in the backhaul load by requiring only scheduling data to be transferred between coordinated eNBs.

Arguably, CoMP is most appealing in the uplink direction since it does not require UE modifications: indeed, users need not be aware that there is any kind of cooperation among receiving eNBs. UEs are merely scheduled for transmission on a set of frequencies that happens to be split among different eNBs, although they still retain standard signaling channels through only one of these eNBs, usually referred to as the serving cell.

In this work we focus on uplink CoMP from a system point of view. Specifically, we are interested in comparing through simulation the performance of uplink CoMP in a heterogeneous scenario with different user participation to CoMP transmissions and CoMP margins. Some works have already investigated uplink CoMP both in simulation and through field trials.

In particular, while in reference 2 has mainly addressed early field trial results in both downlink and uplink CoMP, reference 3 has focused on an uplink CoMP test bed using commercial equipment, comparing the bit-rate gain introduced by CoMP selection combining and soft combining. In reference 4, the authors have simulated a system implementing both uplink CoMP and ICIC (Inter-Cell Interference Coordination), showing that the latter has improved performance when combined with CoMP. Our contribution confirms the findings of previous works as far as the throughput gain for edge users is concerned, but introduces three novel observations that can spur future investigations on CoMP systems and lead to the design of new resource allocation algorithms:

- We look at Heterogeneous scenario where there is no restriction in the type of cells that can be in the CRP set, but simultaneously we introduce clustering option included limited number of Macro and small cells to be acted independently from other clusters in CoMP process.
- We introduce a parameter called CoMP Pool Percentage (CPP), which quantifies the fraction of PRBs that are reserved for UEs using a specific eNB as CRP (out of the resources nominally available to that eNB). Our algorithm show that the setting of CPP must be carefully gauged depending on the number of CoMP users and the scenario.
- We proposed an innovative dynamic algorithm in order to make decision of the CPP value in order to improve the gain for CoMP users while considering the whole network gain.

Combination of the three above mentioned routine and algorithms, according to simulations, confirms an average gain of at least 25% percent for the CoMP users (average over various population) locating in cell boarder while the whole network benefits by 5% gain for all the users (see results section). The algorithm guarantee the more gain for more values of CoMP margin. In other words, the more the population of CoMP users locating in cell borders the more would be the achievable gain.

Based on the article and subject of scheduling for uplink CoMP, the literature review is concluded to the most relevant publication and patents as follows: In Ref no.5 Authors went through the comparison of CoMP in LTE-A with traditional handover like conventional soft/soft handover in 3G network deployment. In their paper they consider mobility management, scheduling and traffic control and show the throughput Gain in cell edges according to different cluster sizes of 3 and 6 cells. The obtained results demonstrate that with minimal changes are required in order to achieve throughout gain in cell edges. It is also shown that the gain with the bull buffer traffic model is more than the case with short files uploaded. In Ref no.6, it is focused on the necessity and possibility of the multi-cell synchronization and channel estimation in field trial cellular scenario in order to deploy CoMP for next generation of cellular network. Dealing with realistic scenarios like interference, fast fading and channel estimations algorithms, they show that in their case of two base-stations median gain of 50% is expected. Their results show increment in fairness among the users and this is what is coincides with theoretical point of view.

In next Reference paper Ref no.7, Authors investigated in exploitation and mitigation of the interference by means of cooperation between eNBs and clusters. The article shows the feasibility of the inter-cell and Intra-cell COMP technique in uplink connections in various field test beds and different backhaul situations. " This article has shown that coordination of cells in wide-area systems is not only beneficial for average spectral efficiency and cell edge data rates, but can also be implemented ".

In Ref no.8, Different theoretical uplink CoMP concepts have been analyzed with a special focus on a constrained backhaul infrastructure and imperfect CSI. The work has shown that strongest CoMP gains can be expected at the cell-edge, and in fact increase for diminishing CSI, whereas gains quickly vanish towards the cell-center. Juho Lee et.al.

In Ref no.9. Suggest different scenarios and specification support of efficient CoMP deployment. Then the article focuses on resource management based on CSI_RS and the enhancement of uplink signals by assigning orthogonal sequences of time-frequency resources by means of coordinated uplink techniques.

In Ref no.10, the paper suggests a novel handover technique assigning decision entity for each CoMP user. This decision entity is a connected serving cell. Gathered data including list of possible serving and CRP cells are reported to current serving cell within a certain decision time window and associated serving cell would decide the current CRP cell and future serving cell. In 11th reference, Authors suggested a cell selection algorithm based on an Uplink CoMP trial in a heterogeneous, Macro-Micro network. They follow a different routine for downlink and uplink connection. In other words, connected serving cell in uplink connection would not be necessarily the downlink connected serving cell. Their algorithm claims a significant Macro cell diversity combining gain where benefits a lower interference level.

Authors in Ref no. 12 investigate in system level evaluation of possible advantages for CoMP – MIMO and they mostly focus on relation between the achieved gain and number of jointly processes cells. Although, negative effects of the above routine are not considered according to the backhaul load and associated complexities of having higher number of contributed cells in Uplink CoMP.

In the patent Ref.no 13, the inventors claimed a new method for uplink multi-point cooperation in LTE-A. They suggested segregating the users into two categories of cooperative and non cooperative users. Considering the user’s priority and channel state by scheduling, the method claims to reduce interface by shared frequency cooperation and to achieve higher throughput for users while the routine maintains the fairness among the users.

In this article, we introduced a novel technique to enhance efficiency in terms of resource allocation and scheduling for Uplink CoMP in LTE-Advanced networks. In order to expand the research, we have introduced some evaluations based on proposed solutions, such as Dynamic CPP Decision, Decision Time Window, and various combinations of scenarios with a different view to the nature of throughput and services of for uplink CoMP in next generation of cellular networks. Simulation results show converging behavior for CPP and intuitively prove the algorithm correctness in order to increase the throughput of edge users and acceptable gain for all users as well as network.

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